ABSTRACT

Title of Thesis:	BIOLOGICAL CONNECTIVITY OF WETLAND AND STREAM HABITATS ON THE DELMARVA PENINSULA USING AQUATIC MACROINVERTEBRATES
	Brock Thomas Couch, Master of Science, 2019
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Biological connectivity is the connection of habitats through the movement of organisms that need to utilize said habitats to maintain their life history. Macroinvertebrate communities in freshwater can create biological connectivity by dispersing between temporary and permanent water sources. For this study, I collected and analyzed seasonal and temporal macroinvertebrate data to understand macroinvertebrate communities in six Delmarva Bays and four surrounding streams and identify potential overlapping genera between habitats. Environmental data was also collected to understand seasonal and temporal similarities and differences between Delmarva Bays and streams. For environmental data, Delmarva Bays and streams were most similar during the winter sampling period and become progressively dissimilar until summer sampling periods. For macroinvertebrate data, there were seventeen overlapping taxa that were found within predator and collector-

gather feeding guilds. From this data, I can conclude that there is a potential for isolated wetlands and streams to have a biological connection.

BIOLOGICAL CONNECTIVITY OF WETLAND AND STREAM HABITATS ON THE DELMARVA PENINSULA USING AQUATIC MACROINVERTEBRATES

by

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Chapter 1: Introduction

Metacommunities are described as communities that are separated within an environment from one another but interact through dispersion (Leibold et al. 2004). For metacommunity ecology, there are four main theoretical concepts that have been developed: patch dynamics (Levins 1969), mass effects (Shmida & Wilson 1983), neutral (Hubbell 2001), and species sorting (Chase 2005). Each of these theories take into account that traits affect ecological patterns and the effect species dispersal has on community composition, but where they disagree is which traits affect ecological patterns and the strength of dispersal's effect on communities. Although these four concepts provide a solid theoretical framework for studies, they can prove challenging to distinguish between when utilizing field data (Heino 2013).

Drawing from those four concepts, biological connectivity is the connection of areas through the movement of organisms that need to utilize said habitats to maintain their life history (Sheaves, 2005). For biological connectivity, the two habitats being utilized by the organisms may or may not be physically connected (e.g., aquatic habitats that are separated by terrestrial habitats). Even though this term comes from the metacommunity literature, it has been adopted by policy when making decisions related to protection of habitats (SWANCC v U.S. Army Corps of Engineers 2001; Rapanos v. United States 2006). Due to policy, this potential connection between isolated habitats has become of interest to science community but has not been investigated in depth (US EPA 2015). Therefore, gaining a better understanding of biological connectivity is important for informing both science and policy. Also, the view that areas are being used in tandem may help show policy makers that these communities are not separate, but rather one community. A group of organisms that have the potential to help gain a better understand of biological connectivity between habitats is macroinvertebrates.

Both lotic (flowing) and lentic (stagnant) freshwater bodies occur within a landscape and together contribute to ecological processes (e.g., nutrient cycling, organic matter cycling, primary production) because of the hydrological (nutrients transfer from surface-water connection) and biological (e.g., energy transfer from dispersing organisms) exchanges between them (Lamberti et al., 2010). With the exchanges, these habitats provide a complex network of sufficient habitat for organisms to develop and mature (Polis et al., 2004). This complex network may allow for energy transfer between habitats by allowing individuals to utilize both types of habitat. On the Delmarva Peninsula in the mid-Atlantic region of the United States, Delmarva Bays and surrounding streams are an example of two component ecosystems interacting within a landscape.

Macroinvertebrate communities in freshwaters can overlap between temporary (e.g., isolated wetlands) and permanent (e.g., streams) water sources (Boulton & Suter, 1986; Collinson et al., 1995; Bogan et al., 2013). For some of these macroinvertebrates, both temporary and permanent water sources are utilized at different times of the year. This is because many macroinvertebrates (e.g., Coleoptera, Hemiptera, and Diptera) have life cycles that begin as aquatic larvae and end as terrestrial adults, which allows larvae to develop in temporary water sources and return to permanent water sources as adults (Wiggins, 1980). For instance, coleopteran adults display a strong dispersal ability that allows them to move from temporary wetlands to more permanent water bodies, such as surrounding streams, to avoid drought or to overwinter only to return to a temporary wetland the following spring/summer to lay their eggs (Landin, 1980; Williams, 1997). Macroinvertebrates with weak dispersal abilities may still utilize both temporary and permanent habitats through surface-water connections, although these connections are much more time-limited. Even though there are some examples of their connection, the literature, overall, treats isolated wetlands and surrounding stream habitats as separate entities within a landscape. Therefore, my overall goal is to define the overlap between the arthropod communities found within isolated wetlands and their adjacent streams on the Eastern Shore of Maryland.

Delmarva Bays are shallow, elliptical depressions that are usually less than 1 ha in size and are found in Delaware and on the Eastern Shore of Maryland (Phillips & Shedlock, 1993). These wetlands are surrounded by upland habitat, which means they have standing water with no permanent hydrological connections to other water bodies and fall within the broad classification of isolated wetlands (Tiner, 2003; U.S. EPA, 2015). Connections to other bodies of waters do exist for part of the year through intermittent streams and groundwater (McDonough, 2015; Phillips & Shedlock, 1993), but disappear as water levels decrease. Because Delmarva Bays do not have a direct connection to permanent surface-water, they rely on precipitation, run-off, or groundwater recharge to fill their basin. During warmer months (i.e., June, July, and August), evaporation causes the water levels in Delmarva Bays to decrease, potentially drying them out (Pickens and Jagoe, 1996). The water within Delmarva Bays is categorized as a calcium-sulfate-type water, meaning it contains high levels of both calcium and sulfate, which creates a low pH environment (Phillip & Shedlock, 1993). Because Delmarva Bays have stagnant water, dissolved oxygen levels are low, which in turn causes low nitrate levels (Phillip et al., 1993). Delmarva Bays hold high amounts of dissolved organic carbon, which leaches from organic matter (e.g., tree leaves) falling directly into the Delmarva Bays or washing into them. Hansson et al. (2005) found that small, shallow wetlands, such as Delmarva Bays, can support an extremely diverse community of amphibians, aquatic birds, and macroinvertebrates. Delmarva Bays harbor up to 45 rare and uncommon plant species and, of those, eight species are globally rare, and one is federally listed species (McAvoy and Bowman, 2002). Due to the seasonality of Delmarva Bays, fish are usually absent, and macroinvertebrates occur in all of the trophic levels (Culler et al. 2014). Although, the communities found within Delmarva Bays are some of the most threatened because it has been estimated that 65% of bay have been altered by agricultural ditching (McAvoy & Bowman 2002, Fenstermacher et al. 2014)

The surrounding streams of Delmarva Bays are slow-moving headwater streams that have soft sand or gravel bottoms. Headwater streams are small streams located at the top of a watershed and can be categorized as ephemeral, intermittent, or perennial (Nadeau & Rains, 2007). Even though they are small, studies suggest headwater streams may encompass up to 80% of the stream distance in many drainage networks (Sidle et al. 2000, Meyer & Wallace 2001, Naiman et. al. 2005). When compared to isolated wetlands, headwater streams have higher dissolved oxygen concentrations and more consistent temperature because of water flow. Water flow, also, carries nutrients received from the surrounding landscape, which is variable depending on land use (e.g., agricultural, urban, forested), throughout watersheds (Johnson et al. 1997). For surrounding streams of Delmarva Bays, they are often situated in a landscape that has high agricultural use. Because of the high agricultural use, streams have the potential to move high amounts of nutrients throughout their network, which will impact the organisms found within them (Strayer, 2006; Clarke, 2008). Similar to isolated wetlands, headwater streams experience a hydroperiod of filling, possibly flooding, in the spring and drying down in the late summer. A key driver in the differences between wetland and headwater stream hydroperiods is the position of the groundwater source. The groundwater source is positioned above the streambed of streams and below the basin of wetlands, which allows the headwater streams to have more consistent water levels compared to wetlands throughout the year (Winter, 1998).

Within Delmarva Bays and surrounding streams, many organisms, which include macroinvertebrates, have adapted to seasonally use both habitats. For isolated wetlands, hydroperiod, the seasonal pattern of the water level (Welsch et al., 1995), has been identified as a driver for adaptation (Williams, 2006). Adaptations, such as faster developmental rates in macroinvertebrates, negate the effects of hydroperiod by avoiding the drying out of isolated wetlands. In a study by Brooks (2000), they found chironomid abundance was highest when the hydroperiod was shortest and abundance decreased as hydroperiod increased. This allows chironomids to utilize habitats that may be unsuitable for other macroinvertebrates, potentially ones that are predators.

Another adaptation of macroinvertebrates that allows them to mitigate the effects of in wetlands hydroperiod is diapause. Diapause is defined by Tauber and Tauber (1981) as, “a hormonally mediated state of low metabolic activity, associated with reduced morphogenesis, increased resistance to environmental extremes, and altered or reduced activity.” Because it is hormonally mediated, diapause requires a specific event to occur in order for it to broken. For example, Horsfall (1956) showed when some mosquitoes go into diapause, a set of events (e.g., decreasing temperature, inundation) needs to occur before they come out of diapause. This adaptation ensures that the mosquito eggs will not hatch before conditions are ideal. This also allows mosquitoes to be some of the first macroinvertebrates within a wetland when it fills, which means they will be able to utilize resources for longer than later arriving macroinvertebrates.

For stream macroinvertebrates, a driving force of adaptations is water flow. For streams with high flow, small macroinvertebrates have flexible and streamlined bodies, reducing drag and allowing them to move crevasses between rocks of the stream bed (Vogel, 1994; Statzner, 1988; Williams, 1972). In contrast, slower moving streams allow for larger bodied macroinvertebrates because they are able to push through the sediments deposited on the stream bed (Lamouroux et al., 2004). Even though permanent streams do not experience as intense of a hydroperiod as isolated wetlands, changes in water flow due to ground water fluctuation can drive macroinvertebrate adaptations (Lamouroux et al., 2004). Aside from flow, headwater stream macroinvertebrates also have to adapt to canopy shade during the spring and summer. When the canopy above headwater streams fills in, primary production is reduced creating an even greater strain on resources within the stream (Lester, Mitchell, & Scott, 1994). These seasonally fluctuations in wetlands and streams allow for potential movement of macroinvertebrates between them.

Even though both isolated wetlands and streams consist of different environments, some macroinvertebrates are able to use both habitats for specific life stages or until isolated wetlands become dry. Because they are different, the hydroperiods can act in tandem to allow macroinvertebrates to move between the isolated wetlands and streams (Figure 1). As mentioned earlier, coleopteran adults found in isolated wetlands will disperse to more permanent water bodies, such as surrounding streams, to avoid drought or overwinter only to return to an isolated wetland the following spring/summer to lay their eggs (Landin, 1980; Williams, 1997). One such species of coleopteran, *Helophorus brevipalpis* (Coleoptera: Helophoridae), found in Sweden seasonally utilizes permanent and temporary waters. As the streams fill and flow increases during the spring, *H. brevipalpis* disperses to isolated wetlands to lay its eggs. Once the water from the isolated wetlands has dried down, the next generation of *H. brevipalpis* returns back to the streams, which have slower flow, to overwinter (Landin, 1980). Species of another order of macroinvertebrates, Hemiptera, can also utilize both temporary and permanent water bodies (Clark, 1928). For example, Baines et al. (2015) showed *Notonecta undulata* (Hemiptera: Notonectidae) actively disperses to a new habitat once they reach a certain body fat content, which suggests energy transfer between habitats. Macroinvertebrates that utilize both permanent stream and temporary wetland habitats add to the complexity of these communities by redistributing biological energy between aquatic habitats separated by terrestrial habitat for most of the year (Polis et al., 2004). Because of this connection, these macroinvertebrates provide insight into the complexity of these habitats by observing them as seasonally joined, rather than as biologically isolated.

For this study, my first objective was to define and compare the physical and chemical conditions of wetlands compared to streams. For my second objective, I compared the aquatic arthropod macroinvertebrate communities of Delmarva Bays and surrounding streams through space and time to identify overlap between the communities. Based on these results, my third objective was to determine specific taxa that utilize both habitats through space and time to understand their roles within the communities.

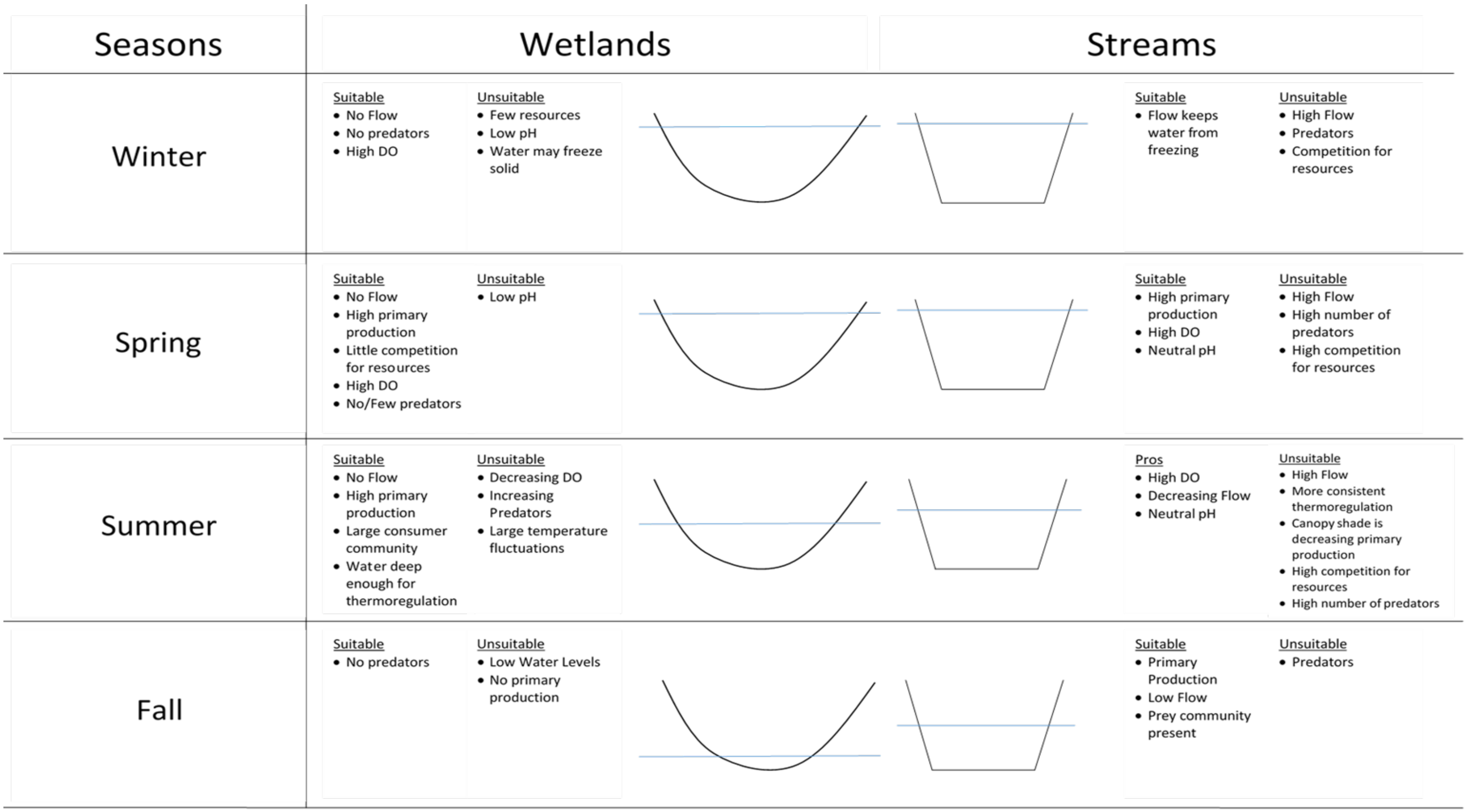

Figure 1. Suitable and unsuitable characteristics of Delmarva Bays and surrounding headwater streams for Macroinvertebrates. During the spring and summer, macroinvertebrates are utilizing the wetlands. In the fall and winter, they are utilizing the streams.
*DO= Dissolved Oxygen

Chapter 2: Methods

Field Sites

For this project, the physical and chemical properties of Delmarva Bay wetlands and streams were assessed to better understand the differences between the habitats throughout the year. Next, the composition of macroinvertebrate communities throughout the year was obtained to identify macroinvertebrates that were utilizing both wetland and streams in tandem, rather than both at the same time. Macroinvertebrates were selected because of their potential to disperse between environments, along with their dominating presences within the habitats. Finally, by combining both environmental and community data, an understanding of when and why overlapping macroinvertebrates moved between habitats.

In 2017, samples were collected from two regions which contained six isolated wetlands and three streams in Queen Anne's and Caroline Counties on the Eastern Shore of Maryland, as well as one stream in Kent County of Delaware (Figure 2-4, Table 1). Wetlands were selected so that were situated within protected areas to help minimize human alteration, since human alteration had the potential to affect wetland habitat suitability for macroinvertebrates by altering environmental conditions (e.g., longer hydroperiod, higher pH, higher nitrate levels). When selecting stream sites, they needed to have flow and not be surrounded by agricultural land use. Stream sites were also selected to be directly adjacent to the wetlands. For the Jackson Lane region, however, I was only able to locate one adjacent stream that had flow and was not surrounded by agricultural land use, due to the fact the surrounding streams had been channelized and turned into agricultural ditches. To avoid sampling agricultural ditches, I selected the nearest stream (JLS2; Table 1) that had flow and was not surrounded by agricultural land use.

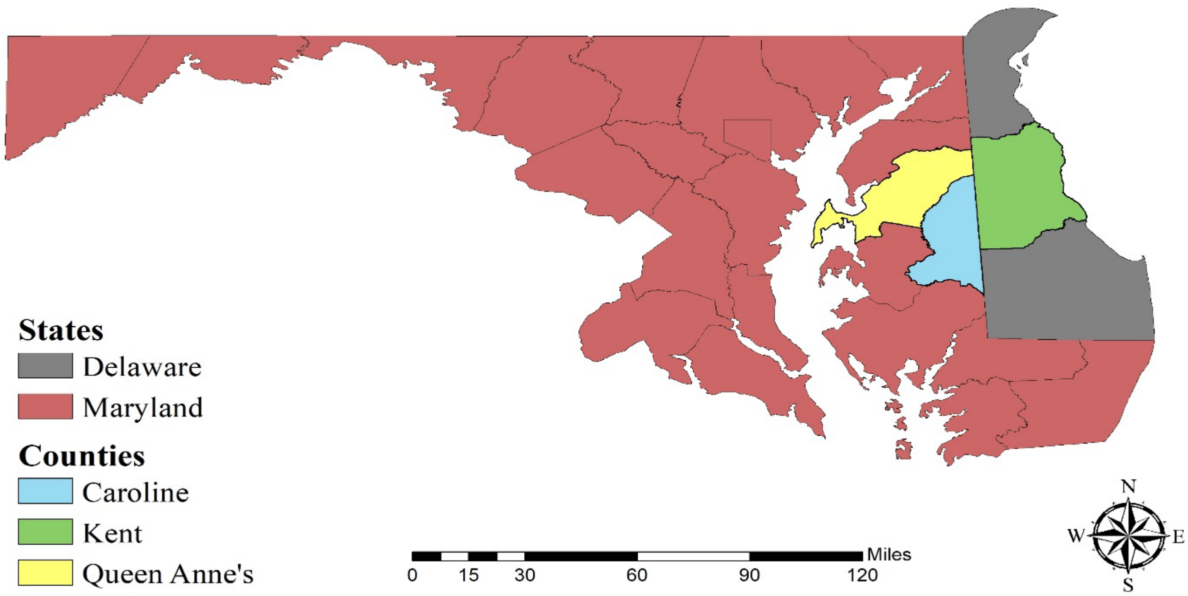

Figure 2. Map of Maryland and Delaware. Counties where sampling sites were located are highlighted with different colors.

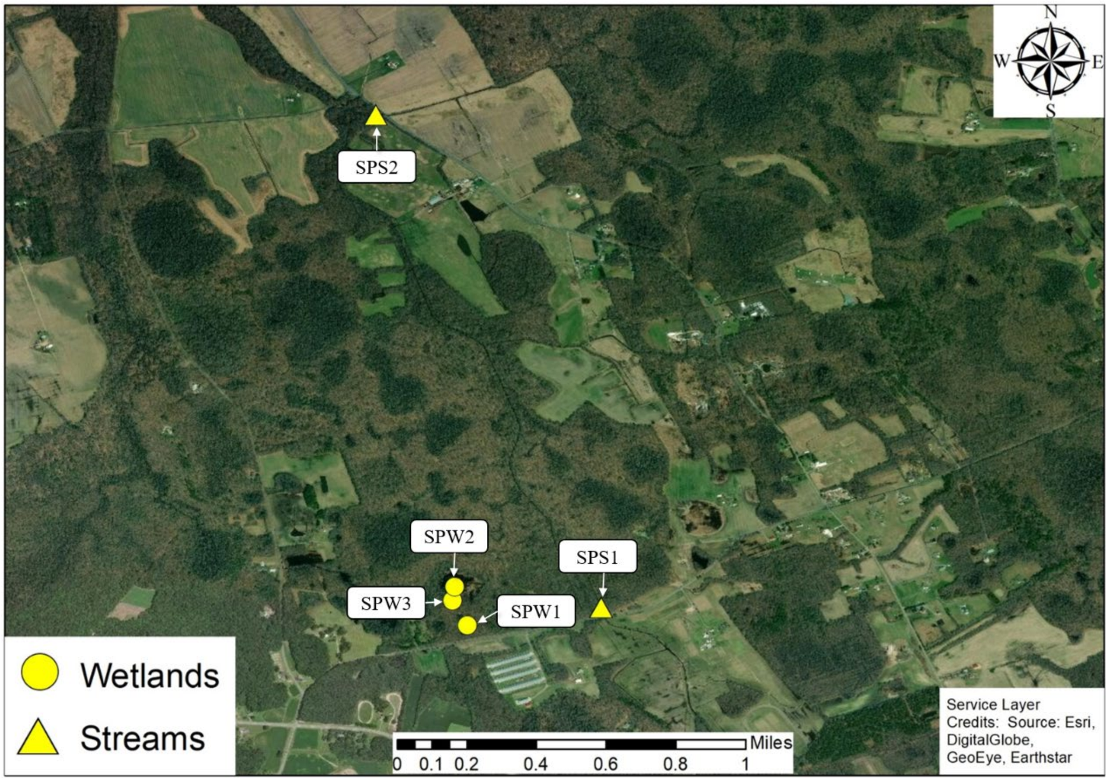

Figure 3. Wetland and stream sites for Slabby Park region. Site codes: SPS = Stream site; SPW = Wetland site. See Table 1 for description of site codes.

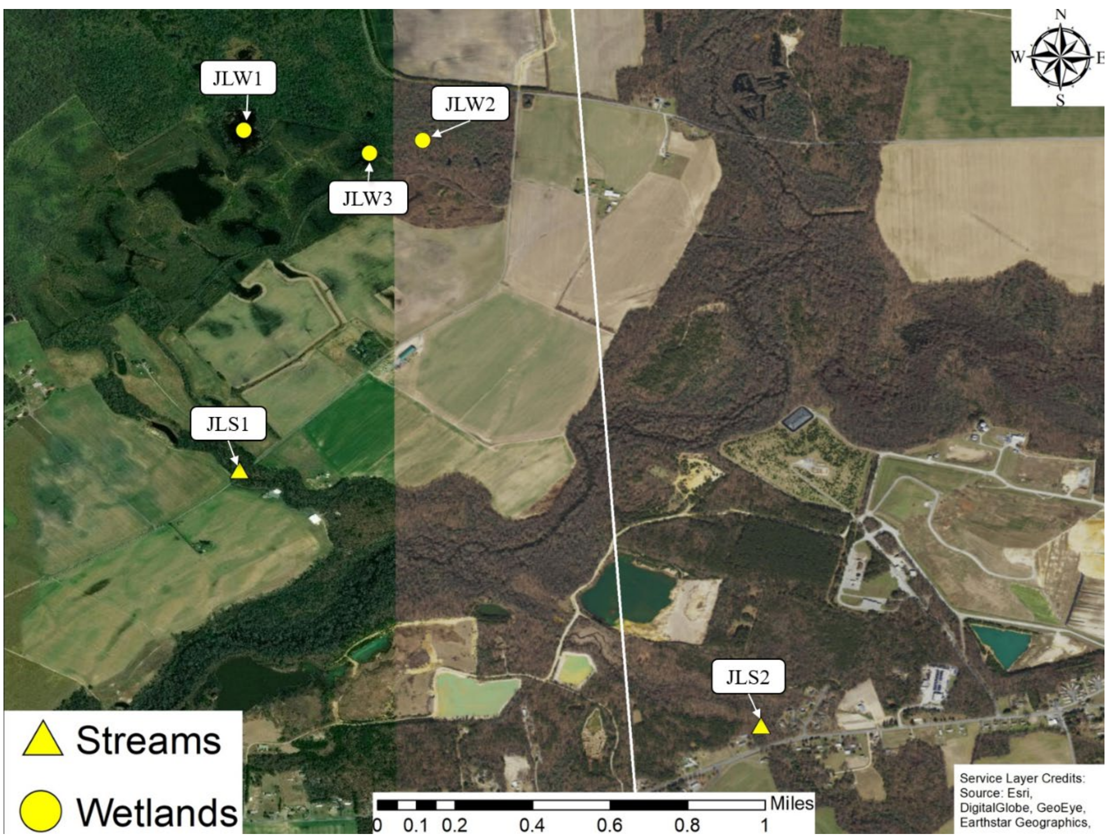

Figure 4. Wetland and stream sites for Jackson Lane region. Site codes: JLS = Stream site; JLW = Wetland site. See Table 1 for description of site codes.

Table 1. Description of wetland and stream sites

Region	Site Code	Site Name	N	W	Wetland Size (ha)	Stream Order
Slabby Park	SPW1	South Wetland	39.14838	-75.81248	0.32	NA
	SPW2	Pristine Pines Wetland	39.1494	-75.81309	0.06	NA
	SPW3	Small Wetland by Pristine Pines	39.14997	-75.81301	2.65	NA
	SPS1	Unicorn Br Stream	39.14911	-75.80693	NA	1^{st}
	SPS2	Dumahel Rd Stream	39.17007	-75.81678	NA	1^{st}
Jackson Lane	JLW1	Pasture Pond Wetland	39.05465	-75.7533	3.65	NA
	JLW2	Small Pool Wetland	39.05427	-75.74661	1.71	NA
	JLW3	Cell 7 Wetland	39.05378	-75.74861	0.19	NA
	JLS1	Jackson Lane Stream	39.04181	-75.75246	NA	1^{st}
	JLS2	Sandtown Br Stream	39.03217	-75.73382	NA	1^{st}

Water Quality and Macroinvertebrate Sampling

At each site, water parameters (i.e., dissolved oxygen, water temperature, water conductivity, and pH) were collected using a YSI Professional Plus Probe (YSI Inc., Yellow Springs, Ohio; Refer to Appendix B). Also, at each site, a macroinvertebrate sample was collected by two people using 500µm D-nets for ten minutes. During the sampling, the D-nets were overturned, and the contents placed in separate bins. After ten minutes, the samples were rinsed through two stacked sieves (9.5mm and 500µm) to separate the macroinvertebrates from large detritus. The remaining sample on the 500µm sieve was then placed into a one-liter Nalgene jar and preserved with 100-percent ethanol. For each site, six samples were collected, once in the fall and winter and twice in the spring and summer, which created a total of 60 samples.

Macroinvertebrate Sample Processing and Identification

For wetland bioassessment, a fixed count of ≥200 individuals provides an unbiased estimate of the community (King and Richardson, 2002). To obtain a subsample, samples were evenly spread across a 7 x 7 gridded tray (one square=16 cm^2) with the squares numbered 1 to 49 (Culler et al, 2014). A square was randomly selected using a random-numbers generator and individuals were removed and counted, excluding Chironomidae. Chironomids were excluded because they are multivoltine and are often habitat generalists, which means they have the potential to overlap between habitats but are not seasonally dispersing between the wetlands and streams. Also, chironomids have the potential to dominate the abundance within stream and wetlands habitats, which would skew the representation of the macroinvertebrate community from the fixed count. If there are not 300 individuals within the first square, another square was selected. This continued until ≥300 individuals were collected, or the entire sample was sorted through (Culler et al., 2014). Sorted individuals were kept in a 10° C walk-in cooler until identified. For identification, regional and local taxonomic keys were used to identify individuals to the lowest taxonomic group, typically genus.

Data Analysis

All data analyses were run in RStudio version 1.1.463 (R Core Team, 2018). For environmental data, boxplots were created using *ggboxplot* from the package *ggpubr* (Kassambara, 2018) to visualize potential differences in environmental factors between wetland and stream habitats. Environmental data was tested for normality in using the command *shapiro.test* from the package *stats* (R Core Team, 2018) to run a Shapiro Wilks test for each variable (dissolved oxygen, specific connectivity, temperature, pH). Because all tests were significant ($p \leq 0.05$), comparisons made in the boxplots were tested for significance ($p \leq 0.05$) using Mann-Whitney tests. To understand the relationship between environmental factors and the change of stream and wetland habitats throughout the sampling periods, a principal component analysis was created using the *prcomp* function from the package *stats* (R Core Team, 2018). A community matrix was created in Excel by entering taxonomic group (i.e., order, family, genus) abundances for sites at each sampling periods (Refer to Appendix A). All taxonomic groups that were present in less than three samples were considered rare and removed from the matrix. For the macroinvertebrate data, a Bray-Curtis dissimilarity matrix was calculated using *vegdist* from the package *vegan* (Oksanen et al., 2018) to assess differences between communities for each season using relative abundances of taxonomic groups. A permutations multiple analysis of variance (PerMANOVA) was run using *adonis* from the package *vegan* (Oksanen et al., 2018) to test the significance of the difference between sites by directly comparing the interaction between sampling period (i.e., Season) and habitat (i.e., wetland and stream) using region (i.e., Slabby Park or Jackson Lane) as a covariant Because sites were repeatedly sampled throughout the year, the command *strata* in *adonis* was used to control for potential similarity between sites between seasons. To visualize the overall overlap between communities, a non-metric multidimensional Scale (NMDS) plot was created using *metaMDS* from the package *vegan* (Oksanen et al., 2018) for both Jackson Lane and Slabby Park by plotting sites on NMDS 1 and 2 axes and using ellipses to group sites by sampling period. PerMANOVAs were separately run for both regions to test the significance of the difference between sites by directly comparing the interaction between sampling period (i.e., Season) and habitat (i.e., wetland and stream). Hierarchical clustering analyses were run for each region using the Ward's method in *hclust* from the package *vegan* (Oksanen et al., 2018) to show which sites were the least dissimilar from one another. Based on the cluster dendrogram, wetland and stream sites will be compared to find the overlapping taxonomic groups within the least dissimilar sites. Once the overlapping taxonomic groups were identified, a bar graph was made to show the possible changes in abundances between stream and wetland sites. These bar graphs will visually show the biological connectivity between wetland and stream sites.

Chapter 3: Results

Water Quality

In general, wetlands had lower average pH, dissolved oxygen, and specific connectivity, whereas temperature was similar between habitats (Figure 5, Refer to Appendix B). For the principal component analysis (PCA), the first two principal components explained 84.5% of variance (PC1: 51.9% & PC2: 32.6%). In the PCA, stream and wetland habitats were both strongly correlated with dissolved oxygen during the winter sampling period (DO; Figure 6). During the second spring sampling and both summer samplings, stream habitats were strongly correlated to regular conductivity and wetland habitats were strongly correlated to temperature (Figure 6). Based on visual observation, water levels in wetlands were the highest during the winter and lowest during the fall. The flow among streams was at its peak during the winter and lowest during the fall sampling period. For the wetlands, three of the sites were open canopy with emergent vegetation (SPW2, JLW1, JLW3) and the other three sites were forested with no emergent vegetation (SPW1, SPW3, JLW2). All of the wetland sites retained water throughout the sampling period, except for SPW2 during the fall sampling period. All of the stream sites were closed canopy and retained water with a consistent flow throughout the sampling period.

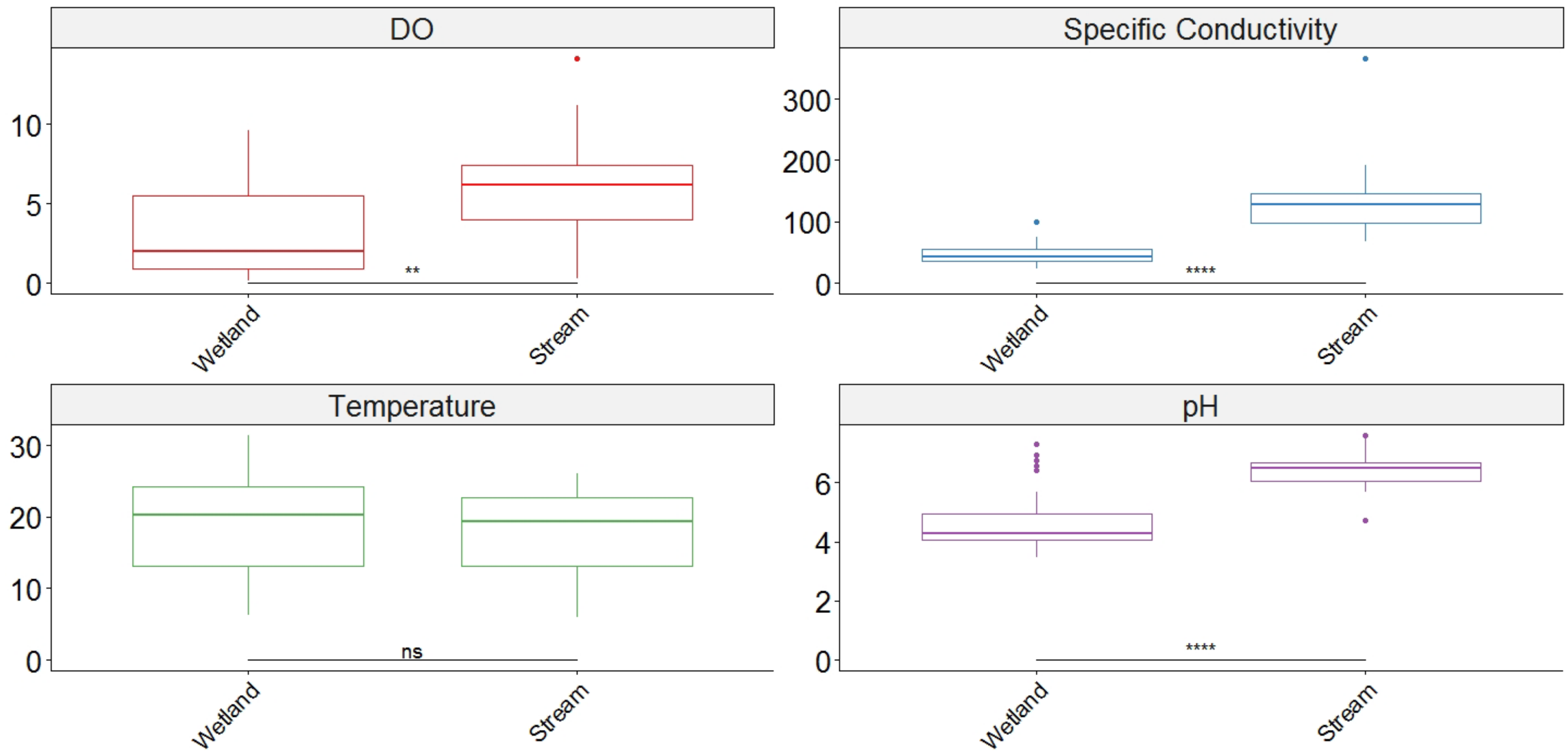

Figure 5. Comparisons of mean environmental measures between habitats. Horizontal lines represent the mean. Vertical lines represent error bars. Dots represent outliers. For significance: ns= $p > 0.05$, ** = $p \leq 0.01$, **** = $p \leq 0.0001$

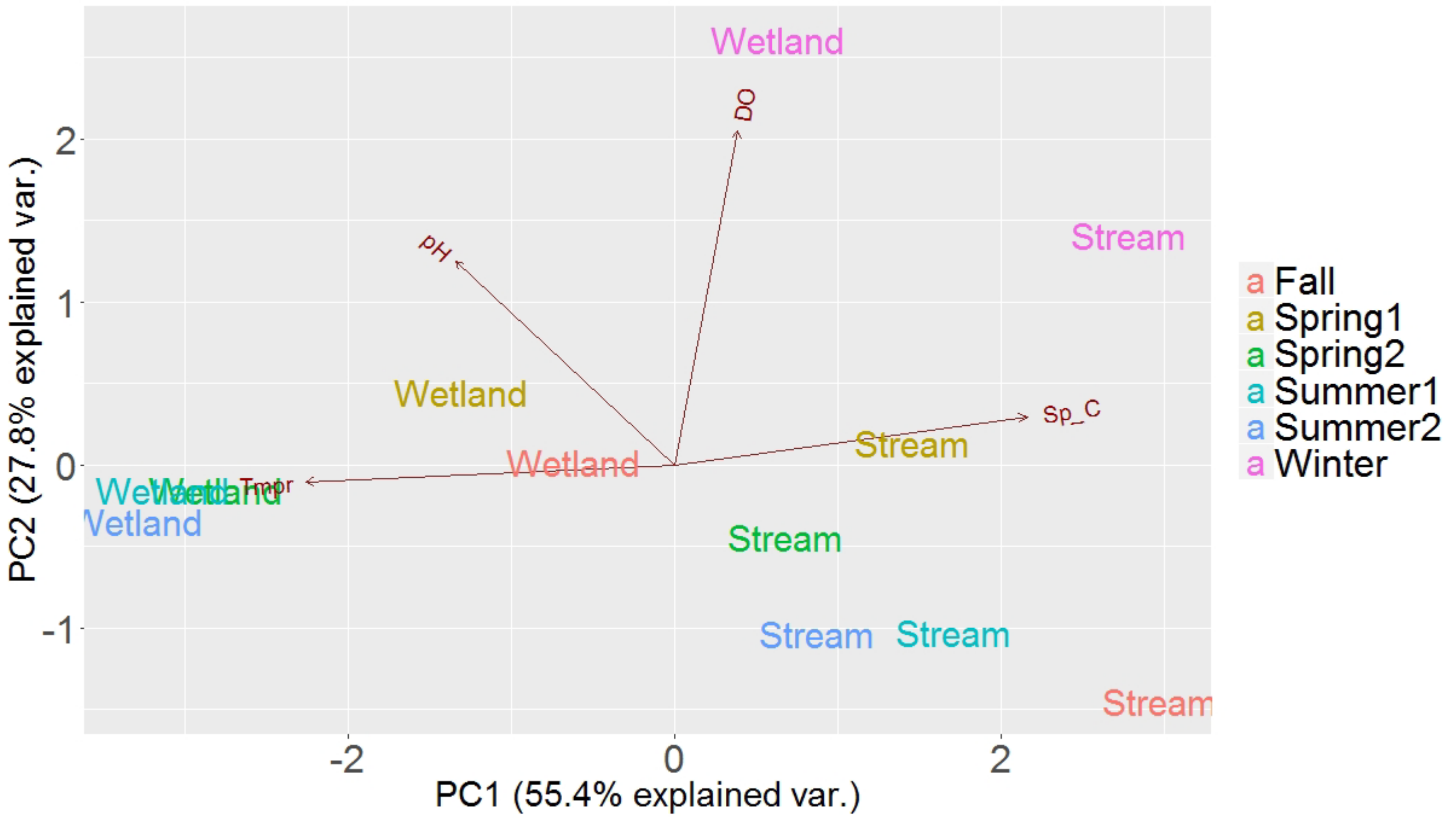

Figure 6. PCA biplot comparing environmental variables of wetland and stream habitats across sampling periods. DO = Dissolved Oxygen; Sp_C = Specific Conductivity; Tmpr = Temperature

Macroinvertebrate Communities

Across all communities, there were 10,106 individuals which belong to 130 different taxonomic groups (Refer to Appendix A). For wetland communities, the winter sampling period had the lowest species richness, diversity, and evenness. They continued to increase until the first summer sampling, after which they consistently decrease until the final sampling period (Figure 7-9). Richness was highest for JLW3 (Table 4) in Jackson Lane during the first summer sampling and was lowest for SPW2 (Table 4) in Slabby Park during the winter (Table 4). Shannon diversity was highest in JLW3 during the first summer sampling and lowest in SPW1 during the first spring sampling (Table 4). Evenness was highest in SPS1 during the fall and lowest in JLW3 during the first spring sampling (Table 4).

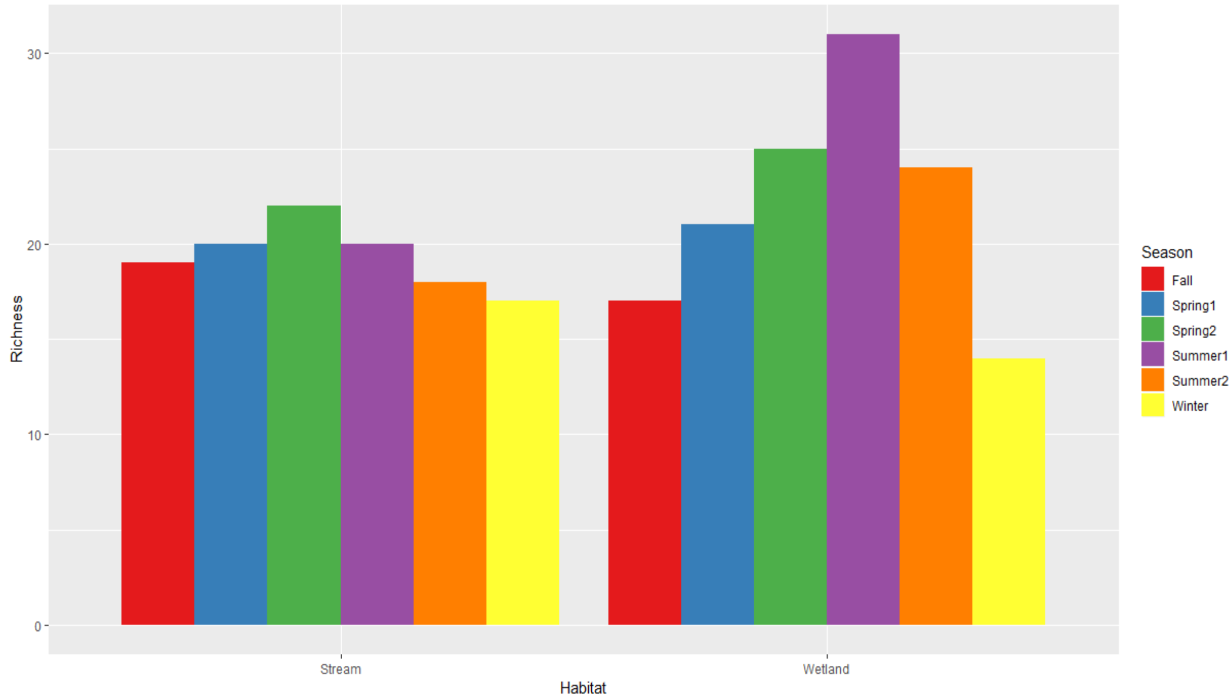

Figure 7. Average species richness of wetlands and streams across sampling periods

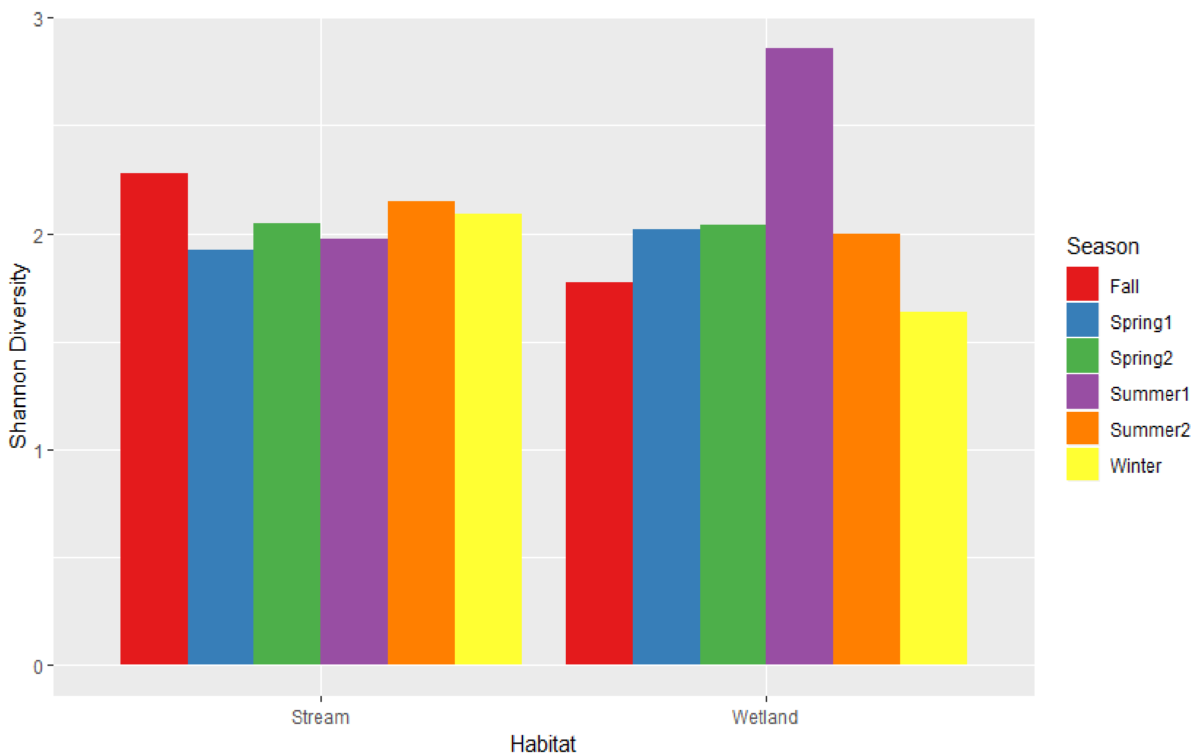

Figure 8. Shannon Diversity of wetlands and streams across sampling periods

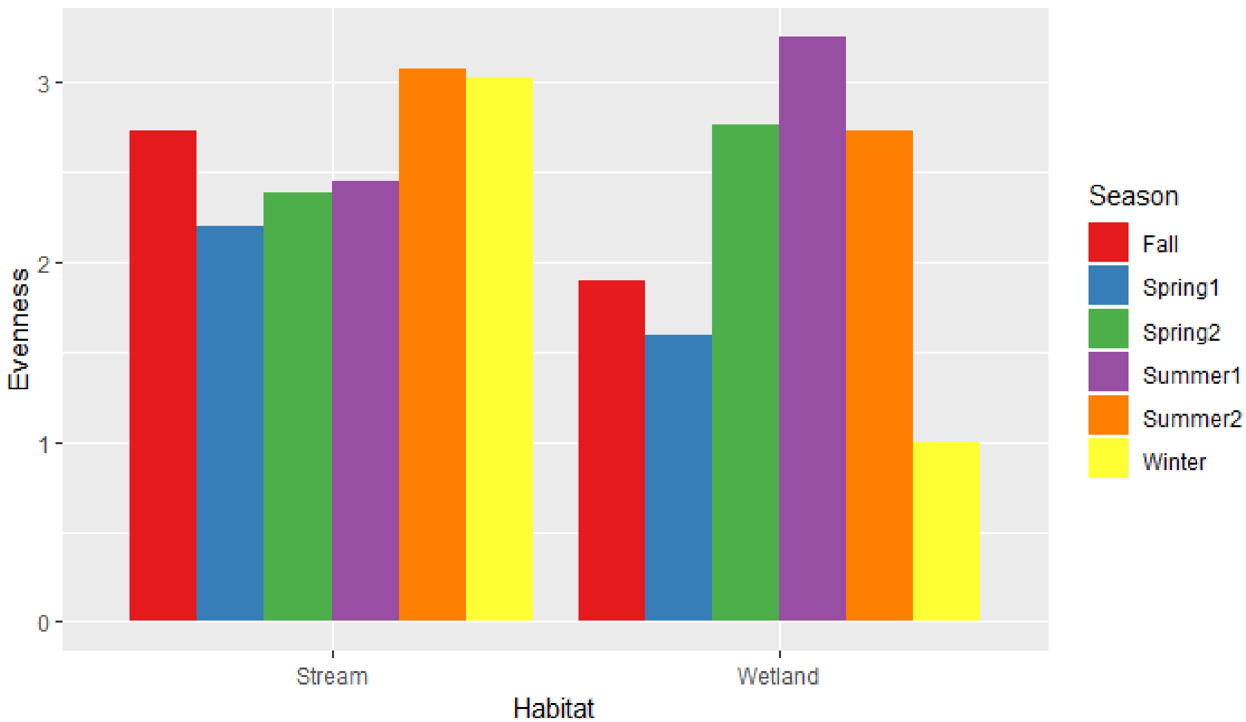

Figure 9. Average evenness of wetlands and streams across sampling periods

Table 4. Species Richness, Shannon Diversity, and Evenness for all sites by sampling period. The fall sampling period for SPW2 has NA for each column because the site was dry.

Site Name	Habitat	Season	Richness	Shannon Diversity	Evenness
JLS1	Stream	Fall	11	2.28	2.07
		Spring1	12	1.89	2.73
		Spring2	13	1.59	0.89
		Summer1	20	1.95	1.09
		Summer2	18	1.32	1.20
		Winter	9	1.52	2.20
JLS2	Stream	Fall	14	1.06	0.59
		Spring1	16	1.93	1.08
		Spring2	17	2.05	1.86
		Summer1	16	1.65	2.39
		Summer2	10	1.50	0.84
		Winter	15	1.42	0.79
JLW1	Wetland	Fall	14	1.98	1.80
		Spring1	14	1.69	2.44
		Spring2	21	1.75	0.98
		Summer1	23	1.53	0.85
		Summer2	24	1.51	1.38
		Winter	12	2.13	3.08
JLW2	Wetland	Fall	9	2.15	1.20
		Spring1	13	1.28	0.71
		Spring2	20	1.23	1.12
		Summer1	12	2.09	3.02
		Summer2	19	0.94	0.52
		Winter	8	1.32	0.74
JLW3	Wetland	Fall	17	0.31	0.28
		Spring1	15	1.31	1.90
		Spring2	23	1.77	0.99
		Summer1	31	0.76	0.43
		Summer2	15	0.86	0.35
		Winter	14	0.23	0.21
SPS1	Stream	Fall	19	1.11	1.60
		Spring1	18	2.02	1.12
		Spring2	22	0.43	0.24
		Summer1	19	0.34	0.13
		Summer2	12	0.32	0.14
		Winter	11	1.01	0.92

SPS2	Stream	Fall	19	1.92	2.77
		Spring1	20	2.04	1.14
		Spring2	18	1.31	0.73
		Summer1	16	0.90	0.36
		Summer2	18	1.09	0.47
		Winter	17	1.20	1.09
SPW1	Wetland	Fall	12	2.25	3.25
		Spring1	15	0.56	0.31
		Spring2	19	2.53	1.41
		Summer1	16	0.63	0.25
		Summer2	14	2.86	1.24
		Winter	8	0.45	0.41
SPW2	Wetland	Fall	NA	NA	NA
		Spring1	17	1.89	2.73
		Spring2	25	1.99	1.11
		Summer1	23	1.98	1.10
		Summer2	20	0.89	0.36
		Winter	7	1.47	0.64
SPW3	Wetland	Fall	15	0.71	0.65
		Spring1	21	0.69	1.00
		Spring2	16	1.64	0.91
		Summer1	14	0.37	0.21
		Summer2	16	0.49	0.20
		Winter	11	0.54	0.23

The overall most abundant taxon was *Caecidotea* (Isopoda: Asellidae) with 4,847 individuals, which accounted for 47.96% of the sampled individuals. *Caecidotea* was the total most abundant group in both wetland habitats and the Slabby Park streams. Although, *Cheumatopsyche* (Trichoptera: Hydropsychidae) was the total most abundant group with 425 individuals for the Jackson Lane streams.

Community comparisons

Across streams, the macroinvertebrate communities consisted of 2853 individuals made up of 86 taxa. For wetlands, the total macroinvertebrate communities consisted of 7254 individuals made up of 89 taxa. Streams and wetlands shared 17 taxa, which accounted for 13% of taxa in the combined macroinvertebrate communities. Within these 17 taxa, there are 7,052 individuals, which accounted for 70% of individuals in combined macroinvertebrate communities. The non-metric multidimensional space (NMDS) plot for with Slabby Park and Jackson Lane combined showed overlap between sites throughout sampling periods (Figure 10).

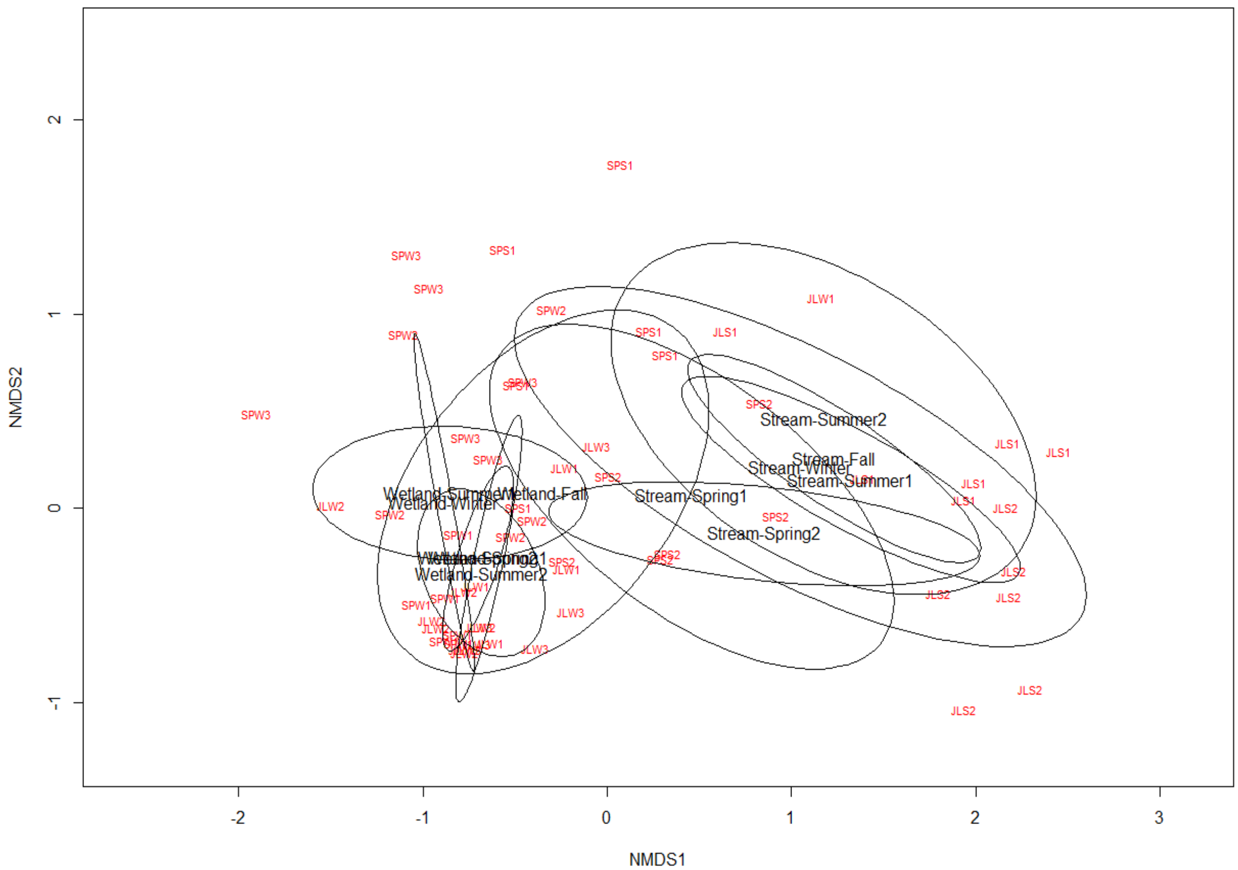

Figure 10. NMDS plot of Jackson Lane and Slabby Park showing the overall overlap between sites across all seasons. Ellipses group sites by habitat and sampling period.

When the permutations multiple analysis of variance (PerMANOVA) was run, there was a significant difference for the interaction between habitat and sampling period (F=1.0652, r^2=0.06921, p=0.023), as well as between regions (F=4.9724, r^2=0.06462, p=0.0001). Because there was a significant difference between regions, separate PerMANOVAs were run for Slabby Park and Jackson Lane communities. These PerMANOVAs showed a significant difference for Jackson Lane (F=1.2827, r^2=0.13142, p=0.038) but not for Slabby Park (F=1.0286, r^2=0.15855, p=0.059). This difference between regions may be due to the fact Jackson Lane wetlands were restored from farmland during the 1970s, although macroinvertebrate communities have been shown to be similar to natural wetlands (Spadafora et al. 2016). Hierarchical cluster dendrograms for Slabby Park and Jackson Lane showed potential overlap between wetland and stream sites between seasons (Figure 11 and Figure 12). Based on the dendrograms, wetland and stream sites were compared to identify

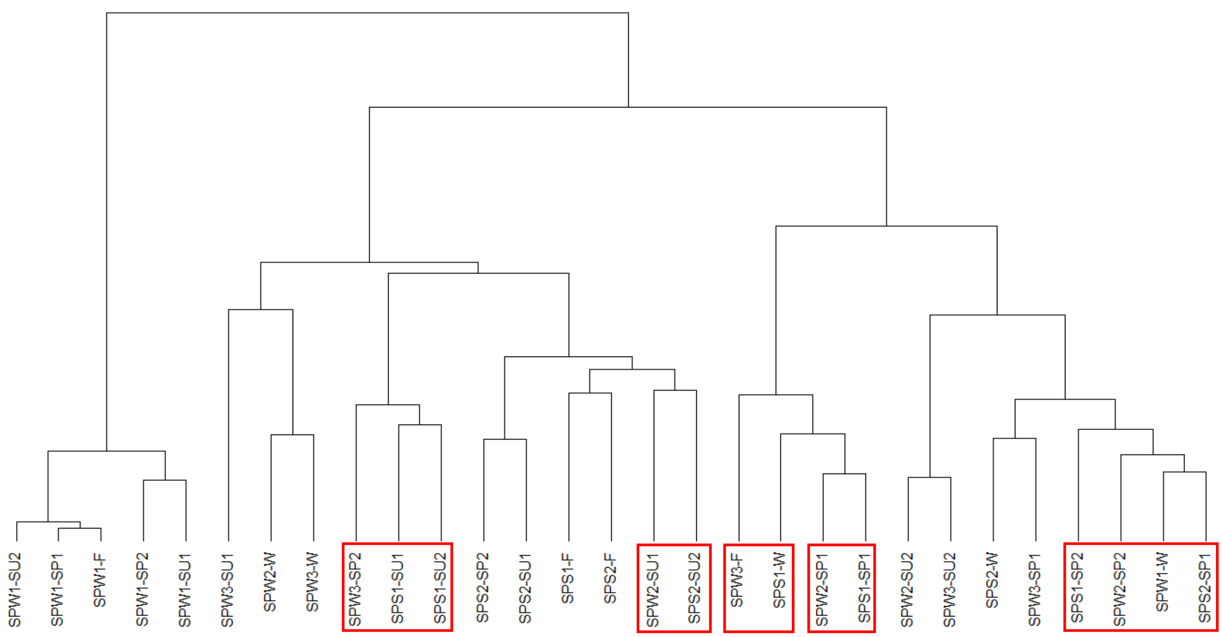

Figure 11. Hierarchical Cluster Dendrogram for Slabby Park. Nodes are named based on site (SPW=Wetland, SPS=Stream) and season (W=Winter, SP1=Spring 1, SP2= Spring 2, SU1= Summer 1, SU2= Summer 2, F=Fall). Red boxes indicate wetland and stream sites that have a potential overlap between communities.

overlapping taxonomic groups.

Within wetlands and streams, collector-gathers were the most abundant (Figure 13). In the wetlands and streams, collector-gathers were the most abundant during the winter and spring samplings (Figure 14). For wetlands, predators comprised the

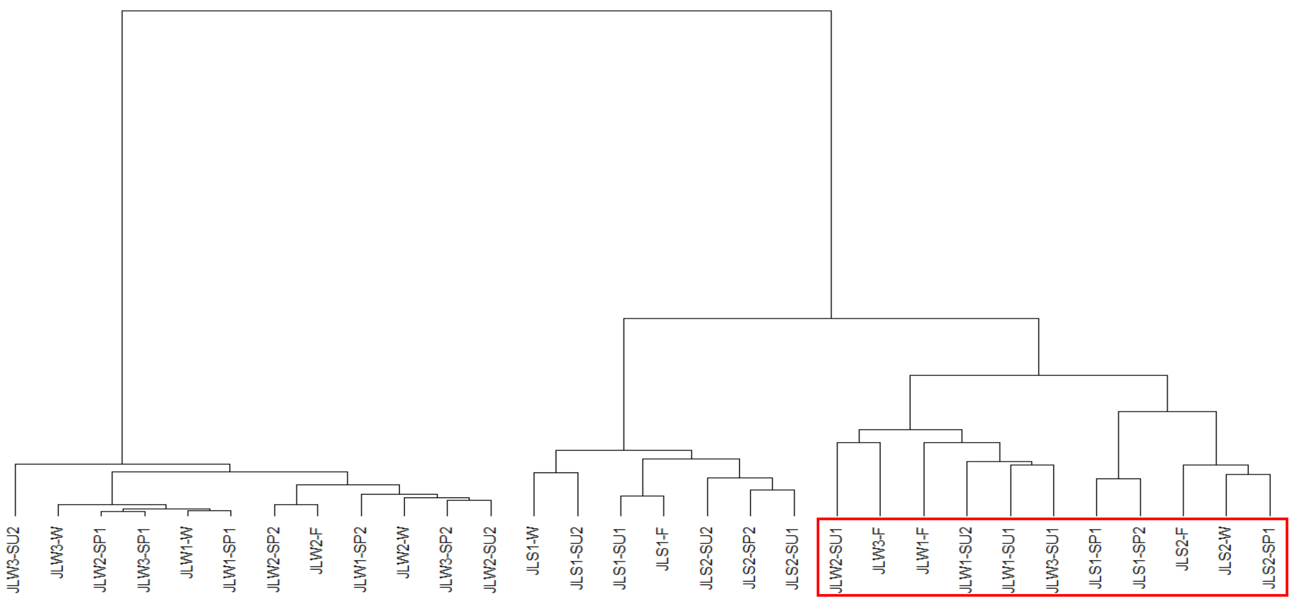

Figure 12. Hierarchical Cluster Dendrogram for Jackson Lane. Nodes are named based on site and season (W=Winter, SP1=Spring 1, SP2= Spring 2, SU1= Summer 1, SU2= Summer 2, F=Fall). Red box indicates wetland and stream sites that have a potential overlap between communities.

largest percent of the community during the first summer sampling with the second summer and fall sampling returning to collector-gathers being the most abundant. For streams, collector-filterers become the most abundant group with predators also increasing. Predators became the most abundant group in second summer sampling. For the fall, predators, collector-gathers, and collector-filterers become relatively similar in abundance. In wetland and stream habitats, shredders were at their highest abundance during the fall sampling (Figure 14).

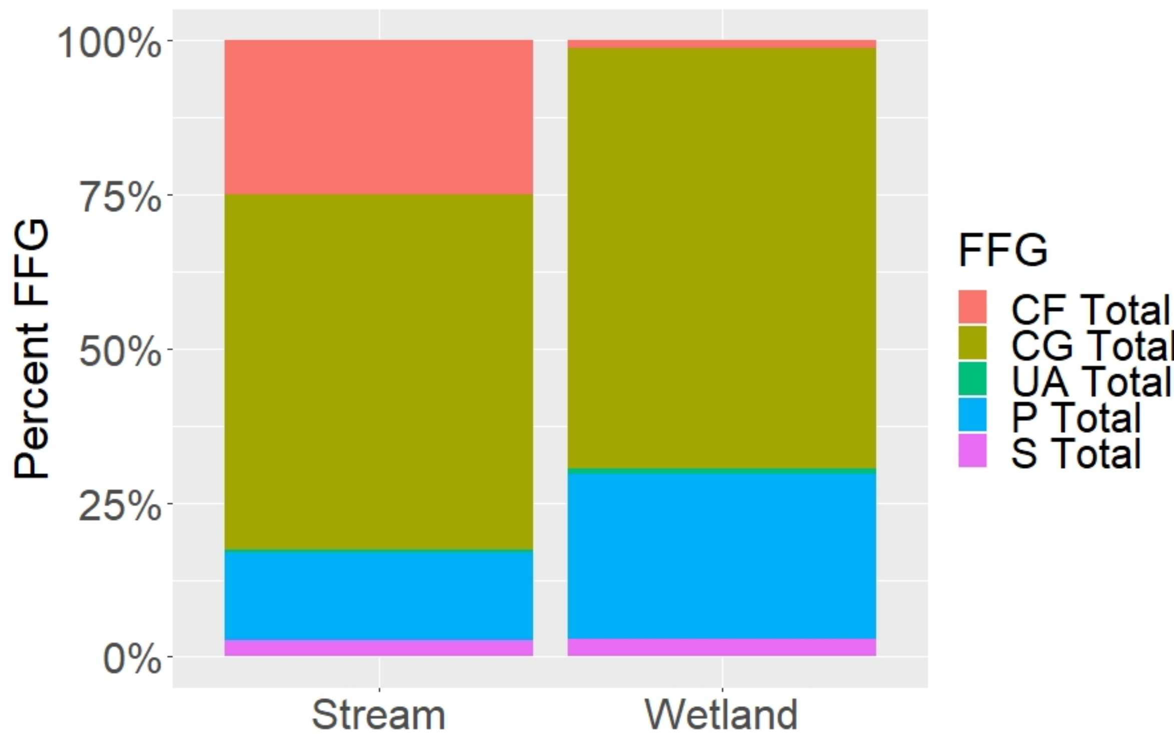

Figure 13. Percent of each functional feeding guild (CF = Collector-filterer; CG = Collector-gatherer; UA = Guild unavailable; P = Predator; S = Shredder) within wetland and stream habitats for the entire sampling period.

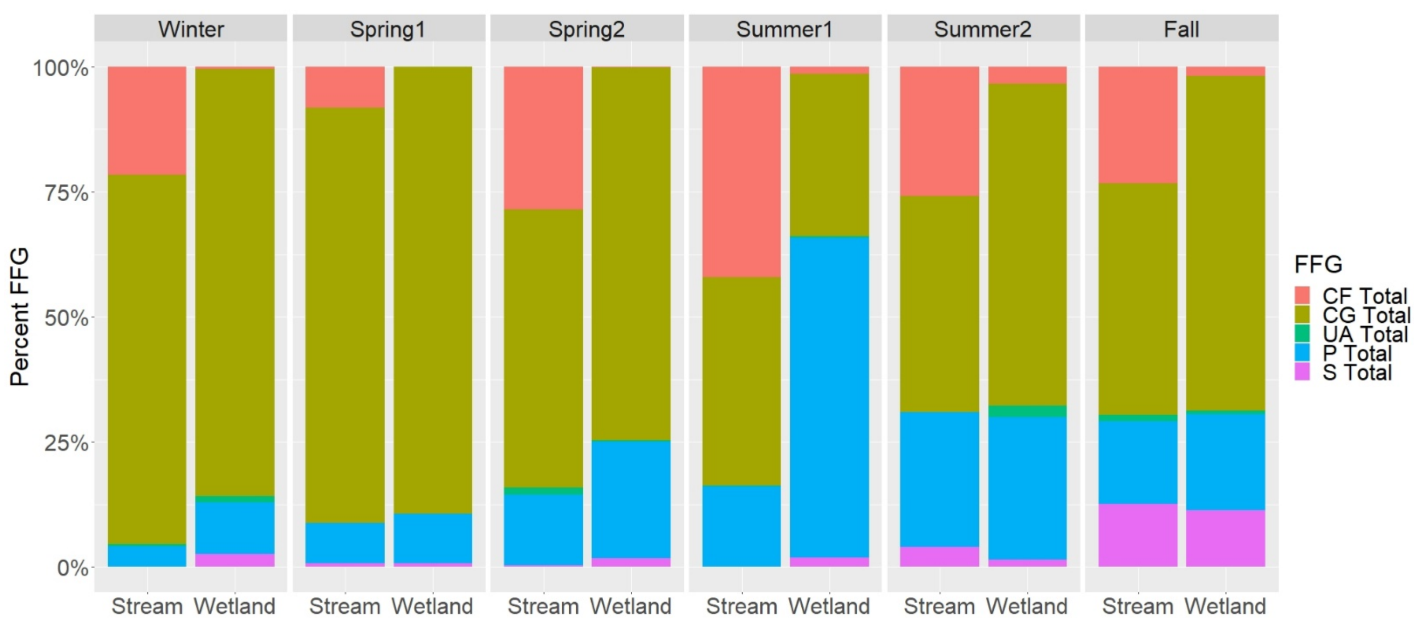

Figure 14. Percent of functional feeding guilds (CF = Collector-filterer; CG = Collector-gatherer; UA = Guild unavailable; P = Predator; S = Shredder) during each sampling period for wetland and stream habitats.

There were seventeen taxa from each region that were overlapping between wetland and stream sites. For Slabby Park, overlapping taxonomic groups were: *Caecidotea* (Isopoda: Asellidae), *Crangonyx* (Amphipoda: Crangonyctidae), Cambaridae (Decapoda), Corixidae nymphs (Hemiptera), *Chauliodes* (Megaloptera: Corydalidae), *Neoporus* (Coleoptera: Dytiscidae), *Hydrobius* (Coleoptera: Hydrophilidae), *Chaoborus* (Diptera: Chaoboridae), Ceratopogonidae pupa (Diptera), and *Bezzia/Palpomyia* (Diptera: Ceratopogonidae) (Table 5). For Jackson Lane, the overlapping taxonomic groups were: *Caecidotea* (Isopoda: Asellidae), *Enallagma* (Odonata: Coenagrionidae), *Haliplus* (Coleoptera: Haliplidae), *Cheumatopsyche* (Trichoptera: Hydropsychidae), *Bezzia/Palpomyia* (Diptera: Ceratopogonidae), Baetidae (Ephemeroptera), *Baetis* (Ephemeroptera: Baetidae), *Caenis* (Ephemeroptera: Caenidae), and Acari (Table 6).

Table 5. Overlapping taxa from Slabby Park. Sampling periods are across the top. Functional Feeding Guilds (FFG) are represented as: CG (Collector/Gatherer), P (Predator). X = Present; 0 = Absent

Taxa	FFG	Fall		Spring 1		Spring 2		Summer 1		Summer 2		Winter	
		Stream	Wetland	Stream	Wetland	Stream	Wetland	Stream	Wetland	Stream	Wetland	Stream	Wetland
Isopoda													
Asellidae													
Caecidotea	CG	X	X	X	X	X	X	X	X	X	X	X	X
Decapoda													
Cambaridae	CG	X	0	X	X	X	X	X	X	0	0	X	0
Diptera													
Ceratopogonidae													
Bezzia/Palpomyia	P	X	0	X	X	0	X	0	X	X	X	0	0
Pupa	P	0	0	0	0	X	X	0	X	0	0	0	0
Chaoboridae													
Chaoborus	P	0	0	0	0	X	X	X	X	0	X	0	0
Hemiptera													
Corixidae													
Nymph	P	X	0	X	X	X	X	X	X	X	0	X	0
Megaloptera													
Corydalidae													
Chauliades	P	0	0	0	0	X	X	0	X	0	X	0	0
Amphipoda													
Crangonyctidae													
Crangonyx	CG	X	X	X	X	X	X	0	X	0	X	X	X
Coleoptera													
Dytiscidae													
Neoporus	P	0	X	0	X	X	X	0	0	0	0	0	0
Hydrophilidae													
Hydrobius	P	0	0	0	X	X	X	0	0	0	0	0	0

Table 6. Overlapping taxa from Jackson Lane. Sampling periods are across the top. Functional Feeding Guilds (FFG) are represented as: CG (Collector/Gatherer), CF (Collector/Filterer), P (Predator), S (Shredder), N/A (Not Applicable). X = Present; 0 = Absent

Taxa	FFG	Fall		Spring 1		Spring 2		Summer 1		Summer 2		Winter	
		Stream	Wetland	Stream	Wetland	Stream	Wetland	Stream	Wetland	Stream	Wetland	Stream	Wetland
Acari (Subclass)	N/A	X	0	0	0	0	0	0	0	0	X	0	X
Isopoda													
Asellidae													
Caecidotea	CG	0	X	X	X	X	X	0	X	0	X	0	X
Ephemorptera													
Baetidae													
NIF	CG	0	0	X	0	0	X	0	X	0	X	0	0
Baetis	CG	X	X	X	0	X	0	X	X	X	X	X	0
Caenidae													
Caenis	CG	0	X	X	0	X	X	X	0	X	0	X	0
Diptera													
Ceratopogonidae													
Bezzia/Palpomyia	P	X	0	X	X	X	X	X	X	0	X	0	0
Odonata													
Coenagrionidae													
Enallagma	P	X	X	0	0	0	0	0	X	0	X	X	0
Coleoptera													
Haliplidae													
Haliplus	S	0	0	X	X	0	X	0	X	0	0	0	X
Trichoptera													
Hydropsychidae													
Cheumatopsyche	CF	X	X	X	0	X	0	X	0	X	0	X	0

Chapter 4: Discussion

Biological connectivity is a connection between habitats through the movement of organisms (Smith et al., 2018). This connection can be created through passive and active dispersal of organisms (Zeller et al., 2012). Here, I described physical and chemical properties of Delmarva Bay wetlands and streams, compared their aquatic arthropod macroinvertebrate communities through space and time, and understood the roles within the communities of taxa that utilize both habitats.

Even though they are both freshwater habitats, isolated wetlands and streams present different general physical and chemical conditions. One major difference between isolated wetlands and streams is flow. An effect of flow is as it decreases so should the DO (Smith & Pearson, 1987). For the wetlands and streams in this study, DO had differing levels with the average DO being higher in streams (Figure 5). When sites were analyzed separately, streams still tended to have a higher DO concentration with the exceptions of JLW1, SPW2 and SPW3 (Refer to Appendix B). The similarity in DO between these wetlands and the streams could have caused by primary production in the wetland. SPW3 did not have primary production within the wetland but it was adjacent and sometimes conjoined with SPW2, which did have primary production. Another difference between the habitats was pH, which was lower in wetlands than streams.

These differences can either intensify or lessen throughout the year. Hydrology creates cyclical fluctuations between habitats throughout the year. The PCA showed this seasonality when comparing wetland and stream habitats because both habitats were correlated with DO during the winter sampling period but became more dissimilar over time with streams becoming correlated with regular conductivity and wetlands becoming correlated with temperature (Figure 6). Delmarva Bays fill during the winter and spring when precipitation is greater than evapotranspiration and begin to dry as evapotranspiration becomes greater then participation throughout the summer and fall, potentially resulting in drying out of the wetlands (Phillips and Shelock, 1993). This drying decreases the water level, which subsequently increases water temperature. Streams also experience hydrological fluctuations in congruence with Delmarva Bays but are often at a lesser degree (Figure 1). These fluctuations effect the flow of the perennial streams by decreasing flow as evapotranspiration increases, which in turn increases the conductivity. Slabby Park and Jackson Lane wetlands and streams followed this same pattern. When comparing the wetlands, SPW2 was the only one to completely dry out. One possible factor of this is because of its open canopy, which has allowed for a large amount of primary production to take place within the wetland. Another factor is that it is a natural wetland. The other open canopy wetlands were within Jackson Lane, which have been restored or created. Even though studies have shown they can support a diverse macroinvertebrate community, the hydrology may have slight differences from a natural wetland (Culler, 2009; Spadafora, 2016). Also, Culler (2014) showed that environmental factors, including tendency to dry, had weak relationships with the assemblage of invertebrate communities within the created and restored Jackson Lane wetlands.

When compared across habitats, richness of the macroinvertebrate communities is similar (Table 3). Macroinvertebrate communities tended to have higher diversity in streams and open-canopy wetlands, when compared to closed-canopy wetlands (Table 4). This is not surprising as previous studies have shown a correlation between primary production increases the diversity of macroinvertebrate communities (Spadafora, 2016). An exception to this was SPW3, which is potentially because it had a surface-water connection at different points during the year. This is not to say that SPW1 did not have surface-water connections with SPW3, but they were not as long lasting as the connections between SPW2 and SPW3. This potential transfer between macroinvertebrate communities due to surface water connections may play an important role in sustaining communities.

Across the sampling periods, wetlands had the highest species richness, diversity, and evenness during the first summer sampling (Figure 7-9). When sites were separated, most of the wetlands followed this same trend for diversity and evenness. For richness, most wetland sites were highest during the spring samplings. For streams, species richness was the highest during the second spring sampling (Figure 7). Diversity was highest during the fall sampling and evenness was highest for the second summer period (Figure 8 & 9). This was also the trend when stream sites were analyzed separately. When combined, these trends follow the prediction that the macroinvertebrates would disperse to the wetlands during the spring and return to the streams in late summer (Figure 1 & 14; Batzer & Wissinger, 1996). This trend was further emphasized by the peak of predators in early summer for wetlands followed by a peak of predators in late summer for streams.

This potential movement between wetland and streams was identified through overlapping taxa between the two habitats. For Slabby Park, the overlapping taxa were either predators or collector-gathers (Table 4). Jackson Lane was similar with all but one taxon, *Cheumatopsyche* (collector-filterer), falling within predator or collector-gather feeding guilds (Table 5). Similarly, studies have found that predators actively disperse between habitats (Nilsson, 1986; Larson & House, 1990; Downie et al., 1998). Unlike this study, these studies have focused specifically on wetland habitats. For collector-gathers, Hershey et al. (1993) found that *Baetis* adults flew 1.6-1.9 km upstream from where they emerged. Even though Hershey et al. only sampled for *Baetis* in stream, this dispersal ability could have allowed them to move from stream sites to wetland sites. In this study, the overlapping taxa were all are active dispersers with *Caecidotea* being an exception. For *Caecidotea* dispersal, McDonough et al. (2010) showed that intermittent streams formed between Delmarva bays and streams to create a direct flow event between the habitats. Because of this flow event, a direct connection is created between the habitats which allows for passive dispersal.

Such as McDonough et al. (2010), studies have shown physical, chemical, and hydrological connections between wetlands and streams that allow for the transfer and transformation of non-living matter (Fritz et al., 2018; Lane et al., 2018). For this study, it was shown that both wetland and stream habitats experience hydrological fluctuations during the year, which creates opportunities for macroinvertebrates to utilize both habitats in tandem. Most macroinvertebrate taxa are exclusive to wetland or stream habitats but there are several taxa that are able to utilize both habitats, which opens the question whether we should be study these streams and wetlands should be viewed as two communities or a metacommunity.

From this study, we are able to gain a larger picture of biological connectivity between wetlands and streams. To gain a better understand of biological connectivity, studies researching species are needed. One of the overlapping taxa for this study were corixid nymphs, which I could not identified with keys. By utilizing DNA techniques (e.g., DNA barcoding), an understanding can be gained of macroinvertebrates' habitat utilization of stream and wetlands. This understanding of habitat utilization will allow us to better inform policy and management decisions regarding wetlands. Currently, isolated wetlands are viewed as separate communities and have no protection offered to them. Because of this, my study helps add to that future research to help inform policy on isolated wetlands through providing a framework to build from by gaining the understanding that isolated wetlands and streams have a potential biological connection through seasonal dispersal, both active and passive, of macroinvertebrates.

Appendix A

Raw Macroinvertebrate Data

Table 2A. Master Macroinvertebrate Community Data for Slabby Park Sites. For each taxon, their functional feeding group (FFG) was represent as either Collector/Gather (CG), Collector/Filterers (CF), Predators (P), Shredders (S), Unavailable (UA). Abbreviations within the column headers represent sites: SPW# = Slabby Park wetlands; SPS# = Slabby Park streams.

Table 2B. Master Macroinvertebrate Community Data for Jackson Lane Sites. For each taxon, their functional feeding group (FFG) was represent as either Collector/Gather (CG), Collector/Filterers (CF), Predators (P), Shredders (S), Unavailable (UA). Abbreviations within the column headers represent sites: JLW# = Jackson Lane wetlands; JLS# = Jackson Lane streams

(Table 2A)

Winter: 15-February-2017

Taxa	FFG	SPW1	SPW2	SPW3	SPS1	SPS2
Isopoda						
Asellidae						
Caecidotea	CG	158	29	14	2	14
Amphipoda						
Crangonyctidae						
Crangonyx	CG	139			20	15
Decpoda						
Cambaridae						
NIF	CG					2
Odonata						
Aeshnidae						
Epiaeschna heros	P			2		
Hempitera						
Corixidae						
Nymph	CG				2	
Dasycorixa	CG				11	
Trichocorixa	P				12	
Sigara	CG				12	5
Megaloptera						
Sialidae						
Sialis	P					1
Coleoptera						
Dytiscidae						
Acilius	P	1				
Agabus	P		3	4		
Elmidae						
Dubiraphia	CG					3
Scirtidae						
Cyphon	S			1		
Trichoptera						
Hydropsychidae						
Hydropsyche	CF					6
Molannidae						
Molanna	CG					4
Phryganeidae						
Ptilostomis	S					2
Diptera						
NIF	UA					1
Simuliidae						
Prosimulium	CF					7
Tabanidae						
NIF	P			1		

Chrysops	P				1	
Ephemeroptera						
Baetidae	CG					1
Caenidae						
Caenis	CG					1
Acari (Subclass)	UA			1		

(Table 2A Continued)

Spring 1: 19-April-2017

Taxa	FFG	SPW1	SPW2	SPW3	SPS1	SPS2
Isopoda						
Asellidae						
Caecidotea	CG	346	90	56	62	101
Amphipoda						
NIF		1	5	20	6	
Amphipoda						
Crangonyctidae						
Crangonyx	CG	3	108	45	204	25
Decapoda						
Cambaridae						
NIF	CG		5	4	4	1
Odonata						
Aeshnidae						
Epiaeschna heros	P					1
Calopterygidae						
Calopteryx	P					3
Lestidae						
Lestes	P			3		
Libellulidae						
NIF	P				1	
Libellula	P		1			
Plathemis	P					1
Hemiptera						
Corixidae						
Nymph	CG	1		1	48	1
Trichocorixa	P					1
Sigara	CG				7	4
Nepidae						
Ranatra	P				1	
Notonectidae						
Notonecta	P				1	
Coleoptera						
Dytiscidae						
Acilius	P	2		1		
Agabus	P	1	4	12		

Desmopachria	P			1		
Liodessus	P	1	3	15		
Laccornis	P		2	9		
Matus	P		1			
Neoporus	P			1		
Elmidae						
Dubiraphia	CG					14
Haliplidae						
Peltodytes	S				9	3
Hydrophilidae						
Hydrophilus	P			2		
Hydrobius	P			4		
Hydrochus	S	1				
Noteridae						
Hydrocanthus	P				1	
Scirtidae						
Cyphon	S			5		
Trichoptera						
Hydropsychidae						
Cheumatopsyche	CF					1
Letptoceridae						
Oecetis	P					10
Molannidae						
Molanna	CG					2
Diptera						
Chaoboridae						
Mochlonyx	P	2	2	6		
Ceratopogonidae						
Bezzia/Palpomyia	P		3	2	1	2
Probezzia	P				1	
Ceratopogon	P				7	
Simuliidae						
Simulium	CF					7
Tabanidae						
NIF	P	1				
Ephemeroptera						
Caenidae						
Caenis	CG				5	
Acari (Subclass)	UA		1			

(Table 2A Continued)

Spring 2: 02-June-2017

Taxa	FFG	SPW1	SPW2	SPW3	SPS1	SPS2
Isopoda						
Asellidae						
Caecidotea	CG	236	102	3	41	42
Amphipoda						
Crangonyctidae						
Crangonyx	CG		23		10	1
Decapoda						
Cambaridae						
NIF	CG		19		4	
Odonata						
Coenagrionidae						
NIF	P		1			
Gomphidae						
Dromogomphus	P					1
Lestidae						
Lestes	P		2	1		
Hemiptera						
Corixidae						
Nymph	CG	23		5	7	
Sigara	CG				16	
Notonectidae						
Nymph	P	3				
Buenoa	P		6			
Notonecta	P	5	5	2		
Megaloptera						
Corydalidae						
Chauliodes	P	24	3		10	
Sialidae						
Sialis	P				1	1
Coleoptera						
Dytiscidae						
Acilius	P	2				
Agabetes	P		1	1		
Agabus	P	4				1
Desmopachria	P		1			
Liodessus	P	2	2			
Laccornis	P		9			
Matus	P		4	1		
Neoporus	P		2	1	1	
Thermonectus	P	1				
Uvarus	P	3	1			

Elmidae						
Dubiraphia	CG				1	12
Gyrinidae						
Dineutus	P				1	1
Hydrophilidae						
Helochares	P				2	
Hydrophilus	P				1	
Hydrobius	P		1	1	2	
Hydrochara	P	1				
Hydrochus	S	4		1		
Paracymus	P				1	
Tropisternus	P	1				1
Scirtidae						
NIF				1		
Cyphon	S		3			
Trichoptera						
Hydropsychidae						
Cheumatopsyche	CF					28
Diptera						
NIF					1	
Chaoboridae						
Pupa	P					1
Chaoboridae						
Chaoborus	P	1		2		2
Ceratopogonidae						
Pupa	P		5		6	3
Bezzia/Palpomyia	P		16	1		
Culicoides	P				1	
Simuliidae						
Simulium	CF				1	64
Tipulidae						
NIF					1	
Tipula	S					1
Ephemeroptera						
NIF	UA					1
Acari (Subclass)	UA	1	1			

(Table 2A Continued)

Summer 1: 27-June-2017

Taxa	FFG	SPW1	SPW2	SPW3	SPS1	SPS2
Isopoda						
Asellidae						
Caecidotea	CG	151	42	6	8	41
Amphipoda						
Crangonyctidae						
Crangonyx	CG		2			

Decapoda						
Cambaridae						
NIF	CG		22		1	
Odonata						
NIF	P		2			
Coenagrionidae						
NIF	P		5			
Gomphidae						
Dromogomphus	P					1
Libellulidae						
NIF	P		7			
Corixidae						
Nymph	CG	2			26	
Hesperocorixa	CG	8	4	2		
Trichocorixa	P				2	
Sigara	CG				10	
Nepidae						
Nepa	P					2
Ranatra	P	1				
Notonectidae						
Nymph	P	1	20			
Buenoa	P		1			
Notonecta	P	6	2	6		
Megaloptera						
Corydalidae						
Chauliodes	P		3			
Sialidae						
Sialis	P					7
Colepotera						
Dytiscidae						
Acilius	P	6		1		
Agabetes	P	4		1		
Cybister	P		1			
Dytiscus	P			1		
Liodessus	P	1	2			
Laccophilus	P		1			
Laccornis	P		19			
Matus	P		1			
Uvarus	P		2			
Elmidae						
Dubiraphia	CG					23
Gyrinidae						
Dineutus	P					5
Hydrophilidae						
Enochrus	CG		2	1		
Hydrochus	S	9				

Trichoptera						
Hydropsychidae						
Cheumatopsyche	CF				3	118
Letptoceridae						
Oecetis	P				2	35
Molannidae						
Molanna	CG				1	13
Molannodes	CF					17
Diptera						
NIF	UA					1
Chaoboridae						
Pupa	P			1		
Chaoborus	P	43		146	1	
Ceratopogonidae						
Pupa	UA		2			
Atrichopogon	CG					1
Bezzia/Palpomyia	P		10			
Ceratopogon	P				2	
Culicoides	P				3	
Culicidae						
Aedes	CF			1	2	
Anopheles	CF				1	

(Table 2A Continued)

Summer 2: 22-August-2017

Taxa	FFG	SPW1	SPW2	SPW3	SPS1	SPS2
Isopoda						
Asellidae						
Caecidotea	CG	296	36	14	1	9
Amphipoda						
Crangonyctidae						
Crangonyx	CG			5		
Odonata						
Aeshnidae						
Epiaeschna heros	P	3	5	2		
Calopterygidae						
Calopteryx	P					6
Gomphidae						
Dromogomphus	P					1
Libellulidae						
NIF	P				1	
Libellula	P				1	1
Sympetrum	P	1				1
Hemiptera						
Corixidae						
Nymph	CG				10	

Sigara	CG					3
Nepidae						
Ranatra	P				3	
Notonectidae						
Nymph	P		1			
Megaloptera						
Corydalidae						
Chauliodes	P		2	2		
Coleoptera						
Dytiscidae						
Desmopachria	P		1			
Liodessus	P		2	3		
Thermonectus	P	1				
Uvarus	P	6	2			
Elmidae						
Dubiraphia	CG				7	
Gyrinidae						
Dineutus	P					1
Hydrophilidae						
Epimetopus	P		1			
Hydrochus	S		1	2		
Paracymus	P	1		1		
Scirtidae						
Cyphon	S		1			
Trichoptera						
Hydropsychidae						
Pupa	CF					1
Cheumatopsyche	CF					4
Letptoceridae						
Oecetis	P					1
Molannidae						
Molanna	CG					6
Molannodes	CF					1
Chaoboridae						
Pupa	P		3	1		
Chaoborus	P	14	1			
Ceratopogonidae						
Bezzia/Palpomyia	P			1		1
Culicidae						
Aedes	CF	1	30	12		
Culex	CF	1	9			
Tabanidae						
NIF	P		9	7		
Chlorotabanus	P			3		
Tipulidae						
NIF	UA				1	1

(Table 2A Continued)

Fall: 30-October-2017

Taxa	FFG	SPW1	SPW2	SPW3	SPS1	SPS2
Isopoda						
Asellidae						
Caecidotea	CG	235		15	11	14
Amphipoda						
Crangonyctidae						
Crangonyx	CG	2		82	2	
Decapoda						
Cambaridae						
NIF	CG				9	13
Odonata						
Aeshnidae						
Epiaeschna heros	P	1		14		
Calopterygidae						
Calopteryx	P				1	2
Libellulidae						
Libellula	P	1				
Pachydiplax	P	1				
Hemiptera						
Corixidae						
Nymph	CG				6	
Dasycorixa	CG				16	
Trichocorixa	P				15	
Sigara	CG				5	1
Megaloptera						
Sialidae						
Sialis	P					1
Coleoptera						
Dytiscidae						
Agabus	P			1		
Liodessus	P	1		1		
Neoporus	P			1		
Uvarus	P			3		
Elmidae						
Dubiraphia	CG					6
Hydrophilidae						
Epimetopus	P	2				
Scirtidae						
Cyphon	S	8		134		
Prionocyphon	S	2				
Trichoptera						
Hydropsychidae						
NIF	CF					1

Cheumatopsyche	CF				2	11
Hydropsyche	CF				1	
Letptoceridae						
Oecetis	P				2	24
Molannidae						
Molanna	CG					16
Molannodes	CF					2
Phryganeidae						
Ptilostomis	S					2
Diptera					1	
Ceratopogonidae						
Atrichopogon	CG			3		
Bezzia/Palpomyia	P					1
Culicidae						
Culex	CF					1
Ephydridae						
Ephydra	S	1		22		
Scatophila	CG	1				
Phoridae						
Pupa	CG	1				
Psychodidae						
Psychoda	CG	1				
Tabanidae						
NIF	P			3		5
Chlorotabanus	P	1				
Tipulidae						
NIF	UA				3	59
Ephemeroptera						
NIF	UA				1	
Baetidae						
Procleon	CF				17	
Caenidae						
Caenis	CF				1	

(Table 2B)

Winter: 17-February-2017

Taxa	FFG	JLW1	JLW2	JLW3	JLS1	JLS2
Isopoda						
Asellidae						
Caecidotea	CG	274	203	270		
Amphipoda						
Crangonyctidae						
Crangonyx	CG		44			
Decapoda						
Cambaridae						
NIF	CG			2		

Odonata						
Aeshnidae						
Basiaeschna	P					1
Calopterygidae						
Calopteryx	P					2
Coenagrionidae						
Enallagma	P				1	
Gomphidae						
Hagenuis	P					1
Progomphus	P					1
Libellulidae						
Libellula	P			2		
Hemiptera						
Corixidae						
Hesperocorixa	CG	1				
Notonectidae						
Notonecta	P			2		
Megaloptera						
Corydalidae						
Chauliodes	P			1		
Nigronia	P					2
Coleoptera						
Dytiscidae						
Liodessus	P	2				
Neoporus	P	13				
Elmidae						
Ancyronyx	CG				15	
Stenelmis	S					21
Haliplidae						
Haliplus	S			22		
Hydrophilidae						
Hydrochus	S	1				
Noteridae						
Hydrocanthus	P			3		
Trichoptera						
Hydropsychidae						
Pupa	CF					2
Cheumatopsyche	CF				9	20
Hydropsyche	CF					7
Letptoceridae						
Oecetis	P					1
Diptera						
Culicidae						
Anopheles	CF	5		1		
Empididae						
Hemerodromia	P					1

Ephydridae						
Brachydeutera	CG			1		
Simuliidae						
Simulium	CF					4
Prosimulium	CF					7
Ephemeroptera						
Baetidae						
Baetis	CF					105
Caenidae						
Caenis	CF				1	
Ephemerellidae						
Eurylophella	CF					2
Acari (Subclass)	UA	1		4		
Lepidoptera						
NIF	UA		1			

(Table 2B Continued)

Spring 1: 20-April-2017

Taxa	FFG	JLW1	JLW2	JLW3	JLS1	JLS2
Isopoda						
Asellidae						
Caecidotea	CG	284	284	376	3	
Decapoda						
Cambaridae						
NIF	CG		2	1		
Odonata						
Aeshnidae						
NIF	P				1	
Calopterygidae						
Calopteryx	P					4
Gomphidae						
Progomphus	P					1
Lestidae						
Lestes	P	4		2		
Libellulidae						
NIF	P			1		
Libellula	P	2				
Hemiptera						
Corixidae						
Nymph	CG		1	7		
Herbidae						
Herbus	P			1		
Notonectidae						
Nymph	P		9			

Megaloptera						
Corydalidae						
Nigronia	P					4
Coleoptera						
Dytiscidae						
Acilius	P		3			
Agabetes	P		1			
Desmopachria	P	1		2		
Dytiscus	P	1				
Liodessus	P	3				
Neoporus	P	2		2		
Uvarus	P	1				
Elmidae						
Ancyronyx	CG			1		5
Stenelmis	S					18
Haliplidae						
Haliplus	S			3	1	
Hydrophilidae						
Hydrobius	P		2			
Tropisternus	P			2		
Trichoptera						
Hydropsychidae						
Cheumatopsyche	CF					2
Hydropsyche	CF					1
Letptoceridae						
Oecetis	P				2	1
Diptera						
Ceratopogonidae						
Bezzia/Palpomyia	P	12			1	4
Ceratopogon	P	1	1			
Simuliidae						
Prosimulium	CF					18
Tipulidae						
NIF	UA				1	
Ephemeroptera						
Baetidae						
NIF	CF				12	
Acentrella	CG				4	
Baetis	CG					19
Caenidae						
Caenis	CG				41	

(Table 2B Continued)

Spring 2: 24-May-2017

Taxa	FFG	JLW1	JLW2	JLW3	JLS1	JLS2
Isopoda						
Asellidae						
Caecidotea	CG	93	227	234	1	
Amphipoda						
Crangonyctidae						
Crangonyx	CG	2	1			
Decapoda						
Cambaridae						
NIF	CG	6				
Odonata						
Aeshnidae						
Epiaeschna heros	P			1		
Calopterygidae						
Calopteryx	P					2
Coenagrionidae						
NIF	P			6		
Gomphidae						
Progomphus	P					1
Lestidae						
Lestes	P	1		1		
Libellulidae						
NIF	P	4		2		
Libellulidae						
Libellula	P	2	1			
Libellulidae						
Perithemis	P			1		
Hemiptera						
Belostomatidae						
Nymph	P	1				
Corixidae						
Nymph	CG	3	3	5		
Hesperocorixa	CG	3				
Notonectidae						
Nymph	P		1			
Notonecta	P	1	4			
Megaloptera						
Corydalidae						
Chauliodes	P	2	2	6		
Coleoptera						
Dytiscidae						
Acilius	P		2			
Coplatus	P	1				

Desmopachria	P	1		11		
Laccornis	P	2				
Matus	P	6	1	5		
Neoporus	P	2	1			
Thermonectus	P		3			
Elmidae						
Ancyronyx	CG				2	5
Stenelmis	S					31
Gyrinidae						
Dineutus	P					1
Haliplidae						
Haliplus	S			5		
Hydrophilidae						
Helobata	P		1			
Hydrobius	P		1			
Hydrochara	P			2		
Tropisternus	P			12		
Noteridae						
Hydrocanthus	P			3		
Scirtidae						
Cyphon	S		1			
Trichoptera						
Hydropsychidae						
Cheumatopsyche	CF				2	111
Hydropsyche	CF					2
Letptoceridae						
Oecetis	P					1
Diptera						
NIF	UA				1	
Chaoboridae						
Chaoborus	P		52			
Ceratopogonidae						
Bezzia/Palpomyia	P			1	3	2
Ceratopogon	P			1		
Culicoides	P			1		
Simuliidae						
Simulium	CF				3	
Prosimulium	CF	1				45
Tabanidae						
NIF	P	1				
Cyclorrhaphous-Brachycera						
Pupa	UA	1	1			
Baetidae						
NIF	CG		2	1		
Baetis	CG				4	52

Taxa	FFG	JLW1	JLW2	JLW3	JLS1	JLS2
Caenidae						
Caenis	CG			1	12	4

(Table 2B Continued)

Summer 1: 28-June-2017

Taxa	FFG	JLW1	JLW2	JLW3	JLS1	JLS2
Isopoda						
Asellidae						
Caecidotea	CG	10	51	6		
Decapoda						
Cambaridae						
NIF	CG	1		1		
Odonata						
NIF	P	3				
Coenagrionidae						
NIF	P	13				
Enallagma	P	3		12		
Ischnura	P	1		3		
Cordulegasteridae						
Cordulegaster	P					1
Libellulidae						
NIF	P	1		6		
Libellula	P			4	1	
Perithemis	P	2		1		
Hemiptera						
Belostomatidae						
Lethocerus	P	1				
Corixidae						
Nymph	CG			1		
Hesperocorixa	CG	4	2	4		
Sigara	CG				1	
Naucoridae						
Pelocoris	P	6		1		
Nepidae						
Nepa	P		1			
Notonectidae						
Nymph	P		5			
Notonecta	P	5	1			
Veliidae						
Rhagovelia	P					1
Megaloptera						
Corydalidae						
Chauliodes	P	1		2		
Nigronia	P					34

Coleoptera						
Dytiscidae						
Cybister	P	3		1		
Desmopachria	P	2				
Liodessus	P			1	1	
Laccornis	P	1				
Elmidae						
Ancyronyx	CG				5	4
Stenelmis	S					35
Gyrinidae						
Dineutus	P				1	
Haliplidae						
Haliplus	S			4		
Hydrophilidae						
Enochrus	CG			2		
Hydrochus	S		1	1		
Tropisternus	P	8		13		
Noteridae						
Hydrocanthus	P	2		1		
Scirtidae						
Cyphon	S			1		
Trichoptera						
Hydroptilidae						
Oxyethira	CG	1				
Hydropsychidae						
Cheumatopsyche	CF				80	148
Hydropsyche	CF				1	15
Letptoceridae						
Oecetis	P				30	8
Molannidae						
Molanna	CG				36	
Diptera						
Chaoboridae						
Chaoborus	P		246	1		
Ceratopogonidae						
Atrichopogon	CG			1		
Bezzia/Palpomyia	P	4		5	4	1
Ceratopogon	P					1
Culicidae						
Aedes	CF			5		
Anopheles	CF	1		3	2	
Culex	CF			3	1	
Empididae						
Hemerodromia	P					1
Sciomyzidae						
NIF	P			2		

Simuliidae						
Simulium	CF				1	48
Ephemeroptera						
Baetidae						
NIF	CG		1	1		
Baetis	CG			1	13	16
Caenidae						
Caenis	CG				9	
Lepidoptera						
NIF	UA	1				1

(Table 2B Continued)

Summer 2: 23-August-2017

Taxa	FFG	JLW1	JLW2	JLW3	JLS1	JLS2
Isopoda						
Asellidae						
Caecidotea	CG	65	127	27		
Decapoda						
Cambaridae						
NIF	CG	1		1		
Odonata						
Calopterygidae						
Calopteryx	P				1	
Coenagrionidae						
NIF	P	3	1			
Coenagrionidae						
Enallagma	P	77	1	1		
Libellulidae						
NIF	P	11	4			
Erythemis	P	3				
Libellula	P	2				
Perithemis	P				1	
Plathemis	P	1			1	
Sympetrum	P	39	17			
Hemiptera						
Belostomatidae						
Lethocerus	P				1	
Corixidae						
Hesperocorixa	CG		1			
Naucoridae						
Pelocoris	P	4				
Notonectidae						
Nymph	P		3			
Buenoa	P		3			
Notonecta	P		6			

Megaloptera						
Corydalidae						
Chauliodes	P	1				
Coleoptera						
Dytiscidae						
Thermonectus	P		1			
Elmidae						
Ancyronyx	CG				8	
Stenelmis	S				2	
Gyrinidae						
Dineutus	P				3	
Hydrophilidae						
Hydrochus	S			1		
Tropisternus	P	5	1	12		
Noteridae						
Hydrocanthus	P	1		1		
Trichoptera						
Hydroptilidae						
Oxyethira	CG	6				
Hydropsychidae						
Cheumatopsyche	CF				8	8
Hydropsyche	CF				1	4
Letptoceridae						
Oecetis	P				5	
Diptera						
Chaoboridae						
Pupa	P	1				
Chaoborus	P		1			
Ceratopogonidae						
Bezzia/Palpomyia	P	8				
Culicoides	P			1	1	
Culicidae						
Anopheles	CF	1		3		
Culex	CF	5		1		
Simuliidae						
Pupa	CF					1
Simulium	CF				1	2
Tabanidae						
NIF	P	1				
Tipulidae						
NIF	UA				1	1
Cyclorrhaphous-Brachycera						
Pupa	UA	1				
Baetidae						
NIF	CG		1			
Baetis	CG		2	1		7

Caenidae						
Caenis	CG				4	
Acari (Subclass)	UA	35				

(Table 2B Continued)

Fall: 01-November-2017

Taxa	FFG	JLW1	JLW2	JLW3	JLS1	JLS2
Isopoda						
Asellidae						
Caecidotea	CG	7	102	28		
Decapoda						
Cambaridae						
NIF	CG	2				
Odonata						
Aeshnidae						
Basiaeschna	P					1
Calopterygidae						
Calopteryx	P					2
Coenagrionidae						
Enallagma	P	7	1	1		1
Cordulegasteridae						
Cordulegaster	P					1
Gomphidae						
NIF	P					1
Libellulidae						
NIF	P	1				
Celithemis	P	2				
Libellula	P	1				
Sympetrum	P	9	5			
Hemiptera						
Gerridae						
Trepobates	P					1
Naucoridae						
Pelocoris	P			2		
Notonectidae						
Notonecta	P			2		
Veliidae						
Microvelia	P				1	
Coleoptera						
Dytiscidae						
Neoporus	P			3		
Elmidae						
Ancyronyx	CG				4	2
Hydrophilidae						
Epimetopus	P			1		
Enochrus	CG			3		

Paracymus	P			3		
Trichoptera						
Hydropsychidae						
Cheumatopsyche	CF	3			17	20
Hydropsyche	CF				6	5
Letptoceridae						
Oecetis	P				6	
Molannidae						
Molanna	CG				10	
Chaoboridae						
Chaoborus	P		41			
Ceratopogonidae						
Atrichopogon	CG			230		
Bezzia/Palpomyia	P				2	2
Phoridae						
NIF	CG			1		
Simuliidae						
Simulium	CF					4
Stratiomyidae						
Nemotelus	CG				1	
Tabanidae						
NIF	P	2		1		
Ephemeroptera						
Baetidae						
Baetis	CF			2		8
Caenidae						
Caenis	CF			6		
Acari (Subclass)						
NIF	UA					1
Lepidoptera						
NIF	UA	1				

Appendix B

Water Quality

Table 3. Environmental Data for all sites. Avg = Average; Max = Maximum; Min = Minimum; StdDev = Standard Deviation. Abbreviations across the top represent sites: SPW# = Slabby Park Wetlands; SPS# = Slabby Park Streams; JLW# = Jackson Lane Wetlands; JLS# = Jackson Lane Streams

(Table 3)

		SPW1	SPW2	SPW3	SPS1	SPS2	JLW1	JLW2	JLW3	JLS1	JLS2
Dissolved Oxygen	Avg	2.00	5.36	3.08	5.48	6.33	3.42	2.86	2.63	5.60	7.06
	Max	6.43	7.93	8.46	10.82	10.77	7.06	5.21	9.61	11.22	14.11
	Min	0.34	1.32	0.60	0.86	2.67	0.22	0.23	0.13	0.26	0.28
	StdDev	2.26	2.75	3.45	3.34	3.26	2.81	1.78	3.97	3.91	4.91
Specific Conductivity (uS/cm)	Avg	56.37	40.36	67.43	141.95	158.33	42.00	32.60	37.73	115.13	129.68
	Max	75.00	48.00	99.70	178.30	365.10	52.40	35.70	63.10	174.60	145.60
	Min	42.60	24.50	45.00	98.40	68.30	35.50	28.70	23.20	84.90	117.00
	StdDev	11.84	9.15	18.26	25.58	113.52	6.63	2.99	13.40	32.71	10.59
Temperature (°C)	Avg	18.45	20.48	16.63	18.22	17.82	19.25	19.73	20.15	18.28	16.75
	Max	28.00	31.30	24.50	24.70	26.00	26.10	27.90	26.80	26.10	22.60
	Min	9.10	8.10	7.30	7.00	6.70	7.80	6.30	11.30	5.90	8.60
	StdDev	6.91	9.46	6.14	7.19	7.08	6.75	8.54	6.87	7.60	5.25
pH	Avg	4.62	4.03	4.22	6.58	6.36	4.94	4.74	5.36	6.61	6.03
	Max	6.42	4.23	6.56	6.80	6.69	6.74	6.92	7.28	7.57	7.48
	Min	3.93	3.67	3.47	6.25	6.02	4.10	3.73	4.19	6.05	4.72
	StdDev	0.93	0.22	1.18	0.20	0.28	0.94	1.15	1.08	0.55	0.90

Literature Cited

Alexander, R. B., E. W. Boyer, R. A. Smith, G. E. Schwarz, & R. B. Moore, 2007. The role of headwater streams in downstream water quality. JAWRA Journal of the American Water Resources Association 43: 41–59.

Association, A. P. H., A. W. W. Association, W. P. C. Federation, & W. E. Federation, 2017. Standard methods for the examination of water and wastewater (Vol. 23). American Public Health Association.

Baines, C. B., S. J. McCauley, & L. Rowe, 2015. Dispersal depends on body condition and predation risk in the semi-aquatic insect, *Notonecta undulata*. Ecology and evolution 5: 2307–2316.

Batzer, D. P., & Wissinger, S. A. (1996). Ecology of insect communities in nontidal wetlands. Annual review of entomology, 41(1), 75-100.

Bogan, M. T., O. Gutierrez-Ruacho, J. A. Alvarado-Castro, & D. A. Lytle, 2013. Habitat type and permanence determine local aquatic invertebrate community structure in the Madrean Sky Islands.

Boulton, A. J., & P. J. Suter, 1986. Ecology of temporary streams—an Australian perspective Limnology in Australia. CSIRO/Junk: Melbourne: 13–327.

Brooks, R. T., 2000. Annual and seasonal variation and the effects of hydroperiod on benthic macroinvertebrates of seasonal forest (“vernal”) ponds in central Massachusetts, USA. Wetlands 20: 707–715.

Chase, J. M. (2005). Towards a really unified theory for metacommunities. *Functional Ecology*, *19*(1), 182-186.

Clark, L. B., 1928. Seasonal distribution and life history of *Notonecta undulata* in the Winnipeg region, Canada. Ecology 9: 383–403.

Clarke, A., R. Mac Nally, N. Bond, & P. S. Lake, 2008. Macroinvertebrate diversity in headwater streams: a review. Freshwater biology 53: 1707–1721.

Collinson, N. H., J. Biggs, A. Corfield, M. J. Hodson, D. Walker, M. Whitfield, & P. J. Williams, 1995. Temporary and permanent ponds: an assessment of the effects of drying out on the conservation value of aquatic macroinvertebrate communities. Biological conservation 74: 125–133.

Culler, L. E., R. F. Smith, & W. O. Lamp, 2014. Weak relationships between environmental factors and invertebrate communities in constructed wetlands. Wetlands 34: 351–361.

Downie, I. S., Coulson, J. C., Foster, G. N., & Whitfield, D. P. (1998). Distribution of aquatic macroinvertebrates within peatland pool complexes in the Flow Country, Scotland. Hydrobiologia, 377(1-3), 95.

Fenstermacher, D. E., Rabenhorst, M. C., Lang, M. W., McCarty, G. W., & Needelman, B. A. (2014). Distribution, morphometry, and land use of Delmarva Bays. *Wetlands*, *34*(6), 1219-1228.

Fritz, K. M., Schofield, K. A., Alexander, L. C., McManus, M. G., Golden, H. E., Lane, C. R., ... & Pollard, A. I. (2018). Physical and Chemical Connectivity of Streams and Riparian Wetlands to Downstream Waters: A Synthesis. JAWRA Journal of the American Water Resources Association, 54(2), 323-345.

Gulis, V., & K. Suberkropp, 2003. Leaf litter decomposition and microbial activity in nutrient-enriched and unaltered reaches of a headwater stream. Freshwater biology 48: 123–134.

Gyulavári, H. A., T. Felföldi, T. Benken, L. J. Szabó, M. Miskolczi, C. Cserháti, V. Horvai, K. Márialigeti, & G. Dévai, 2011. Morphometric and molecular studies on the populations of the damselflies *Chalcolestes viridis* and *C. parvidens* (Odonata, Lestidae). International Journal of Odonatology 14: 329–339.

Hansson, L.A., C. Brönmark, P. Anders Nilsson, & K. Åbjörnsson, 2005. Conflicting demands on wetland ecosystem services: nutrient retention, biodiversity or both?. Freshwater Biology 50: 705–714.

Heino, J. (2013). The importance of metacommunity ecology for environmental assessment research in the freshwater realm. *Biological Reviews*, *88*(1), 166-178.

Horsfall, W. R., 1956. Eggs of flood water mosquitoes III (Diptera, Culicidae). Conditioning and hatching of Aedes vexans. Annals of the Entomological Society of America 49: 66–71.

Hubbell, S. P. (2001). *The unified neutral theory of biodiversity and biogeography (MPB-32)*. Princeton University Press.

Irons III, J. G., L. K. Miller, & M. W. Oswood, 1993. Ecological adaptations of aquatic macroinvertebrates to overwintering in interior Alaska (USA) subarctic streams. Canadian Journal of Zoology 71: 98–108.

Johnson, L., C. Richards, G. HOST, & J. ARTHUR, 1997. Landscape influences on water chemistry in Midwestern stream ecosystems. Freshwater Biology 37: 193–208.

Kassambara, A. 2018. ggpubr: 'ggplot2' Based Publication Ready Plots. R package version 0.2. https://CRAN.R-project.org/package=ggpubr

King, R. S., & C. J. Richardson, 2002. Evaluating subsampling approaches and macroinvertebrate taxonomic resolution for wetland bioassessment. Journal of the North American Benthological Society 21: 150–171.

Lamberti, G. A., D. T. Chaloner, & A. E. Hershey, 2010. Linkages among aquatic ecosystems. Journal of the North American Benthological Society 29: 245–263.

Lamouroux, N., S. Dolédec, & S. Gayraud, 2004. Biological traits of stream macroinvertebrate communities: effects of microhabitat, reach, and basin filters. Journal of the North American Benthological Society 23: 449–466.

Landin, J., 1980. Habitats, life histories, migration and dispersal by flight of two water-beetles *Helophorus brevipalpis* and *H. strigifrons* (Hydrophilidae). Ecography 3: 190–201.

Lane, C. R., Leibowitz, S. G., Autrey, B. C., LeDuc, S. D., & Alexander, L. C. (2018). Hydrological, Physical, and Chemical Functions and Connectivity of Non-Floodplain Wetlands to Downstream Waters: A Review. JAWRA Journal of the American Water Resources Association, 54(2), 346-371.

Larson, D. J., & House, N. L. (1990). Insect communities of Newfoundland bog pools with emphasis on the Odonata. The Canadian Entomologist, 122(3), 469-501.

Leibold, M.A., Holyoak, M., Mouquet, N., Amarasekare, P., Chase, J.M., Hoopes, M.F., Holt, R.D., Shurin, J.B., Law, R., Tilman, D. and Loreau, M., 2004. The metacommunity concept: a framework for multi-scale community ecology. *Ecology letters*, *7*(7), pp.601-613.
Lester, P. J., Mitchell, S. F., & Scott, D. (1994). Effects of riparian willow trees (*Salix fragilis*) on macroinvertebrate densities in two small Central Otago, New Zealand, streams. *New Zealand journal of marine and freshwater research*, *28*(3), 267-276.
Levins, R. (1969). The effect of random variations of different types on population growth. *Proceedings of the National Academy of Sciences*, *62*(4), 1061-1065.
McAvoy, W. A., & P. Bowman, 2002. The flora of coastal plain pond herbaceous communities on the Delmarva Peninsula. Bartonia 81–91.
McDonough, O. T., M. W. Lang, J. D. Hosen, & M. A. Palmer, 2015. Surface hydrologic connectivity between Delmarva Bay wetlands and nearby streams along a gradient of agricultural alteration. Wetlands 35: 41–53.
Meyer, J. L. & J. B. Wallace, 2001. Lost linkages and lotic ecology: rediscovering small streams. In Press, M. C., N. J. Huntly & S. Levin (eds), Ecology: Achievement and Challenge. Blackwell Scientific Publications, Oxford: 295–317.
Nadeau, T.L., & M. C. Rains, 2007. Hydrological connectivity between headwater streams and downstream waters: how science can inform policy. JAWRA Journal of the American Water Resources Association 43: 118–133.
Naiman, R. J., H. Decamps, & M. E. McClain, 2010. Riparia: ecology, conservation, and management of streamside communities. Academic Press.
Nilsson, A. 1986. Community structure in the Dytiscidae (Coleoptera) of a northern Swedish seasonal pond. Annales Zoologici Fennici, 23(1), 39-47.
Oksanen, J., Blanchet, F.G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P.R., O'Hara, R.B., Simpson, G.L., Solymos, P., M. Stevens, H.H, Szoecs, E., & Wagner, H. 2018. vegan: Community Ecology Package. R package version 2.5-3. https://CRAN.R-project.org/package=vegan
Phillips, P. J., J. M. Denver, R. J. Shedlock, & P. A. Hamilton, 1993. Effect of forested wetlands on nitrate concentrations in ground water and surface water on the Delmarva Peninsula. Wetlands 13: 75–83.
Phillips, P. J., & R. J. Shedlock, 1993. Hydrology and chemistry of groundwater and seasonal ponds in the Atlantic Coastal Plain in Delaware, USA. Journal of Hydrology 141: 157–178.
Pickens, R. M., & C. H. Jagoe, 1996. Relationships between precipitation and surface water chemistry in three Carolina bays. Archiv für Hydrobiologie 137: 187–209.
Polis, G. A., M. E. Power, & G. R. Huxel, 2004. Food webs at the landscape level. University of Chicago Press.
Rapanos v. United States. 547 US 715. Supreme Court of the United States. 2006.
R Core Team. 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Solid Waste Agency of Northern Cook County (SWANCC) v. the U.S. Army Corps of Engineers. 531 US 159. Supreme Court of the United States. 2001

Sheaves, M. (2005). Nature and consequences of biological connectivity in mangrove systems. Marine Ecology Progress Series, 302, 293-305.

Shmida, A. V. I., & Wilson, M. V. (1985). Biological determinants of species diversity. *Journal of biogeography*, 1-20.

Sidle, R. C., Y. Tsuboyama, S. Noguchi, I. Hosoda, M. Fujieda, & T. Shimizu, 2000. Stormflow generation in steep forested headwaters: a linked hydrogeomorphic paradigm. Hydrological Processes 14: 369–385.

Smith, R. E. W., and Pearson, R. G. (1987). The macro-invertebrate communities of temporary pools in an intermittent stream in tropical Queensland. Hydrobiologia, 150, 45–61.

Smith, L. L., Subalusky, A. L., Atkinson, C. L., Earl, J. E., Mushet, D. M., Scott, D. E., ... & Johnson, S. A. (2018). Biological Connectivity of Seasonally Ponded Wetlands across Spatial and Temporal Scales. JAWRA Journal of the American Water Resources Association.

Solid Waste Agency of Northern Cook County (SWANCC) v. the U.S. Army Corps of Engineers, 531 US 159, Supreme Court of the United States (2001)

Spadafora, E., A. W. Leslie, L. E. Culler, R. F. Smith, K. W. Staver, & W. O. Lamp, 2016. Macroinvertebrate community convergence between natural, rehabilitated, and created wetlands. Restoration Ecology 24: 463–470.

Statzner, B., J. A. Gore, & V. H. Resh, 1988. Hydraulic stream ecology: observed patterns and potential applications. Journal of the North American benthological society 7: 307–360.

Strayer, D. L., 2006. Challenges for freshwater invertebrate conservation. Journal of the North American Benthological Society 25: 271–287.

Tiner, R. W., 2003. Geographically isolated wetlands of the United States. Wetlands 23: 494–516.

Tyndall, R. W. (2000). Vegetation change in a Carolina bay on the Delmarva Peninsula of Maryland during an eleven-year period (1987-1997). Castanea, 155-164.

U.S. EPA. Connectivity of Streams and Wetlands to Downstream Waters: A Review and Synthesis of the Scientific Evidence (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-14/475F, 2015.

Vogel, S., 1994. Life in moving fluids: the physical biology of flow. Princeton University Press.

Welsch, D. J., D. L. Smart, J. N. Boyer, P. Minkin, H. C. Smith, & T. L. McCandless, 1995. Forested Wetlands-Functions, Benefits and the Use of Best Management Practices. United States Department of Agriculture Forest Service.

Wiggins, G. B., R. J. Mackay, & I. M. Smith, 1980. Evolutionary and ecological strategies of animals in annual temporary pools. Archiv für Hydrobiologie supplement 58: 206.

Williams, D. D., 1997. Temporary ponds and their invertebrate communities. Aquatic conservation: marine and freshwater ecosystems 7: 105–117.

Williams, R., 1972. The abundance and biomass of the interstitial fauna of a graded series of shell-gravels in relation to the available space. The Journal of Animal Ecology 623–646.
Winter, T. C., 1998. Ground water and surface water: a single resource. DIANE Publishing Inc.
Wood, P. J., J. Gunn, H. Smith, & A. Abas-Kutty, 2005. Flow permanence and macroinvertebrate community diversity within groundwater dominated headwater streams and springs. Hydrobiologia 545: 55–64.
Zeller, K.A., K. McGarigal, and A.R. Whiteley. 2012. “Estimating Landscape Resistance to Movement: A Review.” Landscape Ecology 27 (6): 777–97.